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Effective Team Performance Under Stress
and Normal Conditions: An Experimental
Paradigm, Theory and Data for Studying
Team Decision Making in Hierarchical
Teams with Distributed Expertise

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The report describes a program of research addressing decision making in hierarchical teams with distributed expertise. A theory of such decision making is presented along with empirical research related to the theory. Then a team simulation exercise was developed to address team decision for four person teams. This exercise presents teams with problems that require gathering and sharing information prior to reaching a team decision and also allow for the assignment of team members to roles that differ in areas of expertise. This exercise, performed on four networked computers, allows for the assessment of a large number of team behaviors. Along with the exercise, repeated measures regression is used as a means of analyzing team data by taking advantage of the statistical power available at various levels of analysis. Several studies were conducted to assess the viability of theory and to look at a number of other issues of decision making.

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Effective Team Performance Under Stress and Normal Conditions: An Experimental Paradigm, Theory and Data for Studying Team Decision Making in Hierarchical Teams with Distributed Expertise

Much of human behavior in organizations occurs in teams. This is particularly true at present due, in part, to a shift in the 19   and early 1990s from organizing work around individual jobs toward organizing around larger clusters of tasks assigned to teams (Ilgen, in press). Given the ubiquitousness of groups or teams, it is not surprising that a great deal of research has been conducted on them. Much of the early work fell within the domain of small group research. Classic works by Lewin, Lippett and White (1939) comparing democratic and autocratic leadership styles and that of Stouffer and others showing the effects of teams on combat performance during World War II (Stouffer, Suchman, DeVinney, Star, & Williams, 1949) helped to stimulate research on groups from the 1940s to the present. The amount of research activity has varied across time and progress has been spotty (Steiner, 1974; 1983). However, for reasons both of practical importance and of theoretical interest, decision making in small groups or teams has been one of the most frequently studied outcomes in the applied social sciences.

Although attempts have been made to develop general theories of small group behavior, in our opinion, the greatest progress has been made when attention is focused on a subdomain of group or team phenomenon. Team or small group decision making is an excellent example of this. Restricting attention to group decisions is a significant narrowing of the field. Yet, within small group decision making, most research has been further limited to groups of individuals who work together to reach a consensus decision (Davis, 1992). Group members may be homogeneous or heterogeneous in terms of backgrounds, share or not share common knowledge bases, or differ on a wide variety of variables, but typically they all have, at least in principle, an equal vote when it comes to reaching a decision for the group. The settings and decision problems have also varied widely, but interest in specific topics is typically dictated by important societal conditions, such as the case of the large literature on jury decision making (Davis, Bray, & Holt, 1977). Davis (1992) recently edited a special edition of <u>Organizational Behavior and Human Decision Making</u> dedicated exclusively to work on consensus decision making in small groups.

The work of the research effort reported here also addresses small group or team decision making. In contrast to consensus decisions, it deals with decisions in groups or teams with two distinguishing characteristics. First, we were interested in teams with status differences among the members, in those in which one member is held primarily responsible for the decision. A second distinguishing characteristic was that members bring to the group or team different areas of expertise; all were not equal as to the knowledge and information they bring to the decision problem. We shall refer to the latter condition as distributed expertise. It is our contention that hierarchical teams with distributed expertise are extremely common in all kinds of organizations. Command and control teams, managerial staffs, hospital emergency room teams, congressional committees, and research teams of graduate students working with a professor are just a few of the many examples of teams that fit the model of a hierarchical team with distributed expertise.

Overview

This report describes a three year effort directed at understanding team decision making in hierarchical teams with distributed expertise. It begins by developing a model or theory of team decision making based on a team-level construal of an individual decision making model. Following the presentation of the theory, a simulation for team decision making is described. This simulation was designed to present four person teams with decisions based on multi-attribute decision objects. The teams all consist of a leader and three subordinates who share some common knowledge base but also each possess some unique levels of expertise. By working together and sharing information in a networked computer laboratory, the teams made decisions. Although all of the research described here has used the same decision scenario, the software for the simulation has been designed so that it can be used for a wide variety of decisions that share a multi-attribute structure.

Following the presentation of the simulation, two methodological issues are addressed. The first of these is a report of research that was designed to assess the validity of key constructs of interest in the simulation. The second describes the use of repeated measures regression as a way to analyze team data with more than one level of analysis. Nearly all team research is based on variables that occur at least at the level of the individual, the dyad, and the team level. Yet, frequently, these data are all aggregated to the team level creating a severe loss in

statistical power. Repeated measures regression is proposed as a means for analyzing data at the lowest level appropriate for the constructs of interest and, therefore, attaining as much statistical power as is possible from the design. Finally, with the description of the simulation, the validity of constructs measured in the simulation, and a data analytic method, empirical studies are reported which provide support for the theory and demonstrate the impact of critical team variables key constructs in the theory.

In presenting this work, descriptions of it are presented in sufficient detail for this report to provide a stand-alone account of the research. However, for more detail, the reader is referred to specific technical reports, journal articles, book chapters, and theses and dissertations that were written as part of the research effort. A complete listing of this work appears in the Appendix.

A Multi-Level Theory of Team Decision Making

Models most frequently evoked to study team decision making begin with the outcomes of decisions and build process around them. Models have been developed for teams making consensus rather than hierarchical decisions. Two social combination models (Kerr, 1992) dominate the literature. One, Social Decision Scheme (SDS) (Davis, 1973) focuses on decisions with a small number of alternatives (primarily two, such as guilty/not guilty, correct/incorrect). It models choices based on the size of the group and possible distributions of preferences for each alternative across group members. The other, Social Transition Scheme (STS), is also concerned with decisions involving a finite number of choices, but it attempts to model transitions in distributions of possible choices among participants over the life of the team, from its formation to reaching a final decision (Kerr, 1992). In both cases, the models begin with team composition and model team level choice distributions.

The model proposed here differs in several respects from SDS and STS. First, it begins not with the decision outcomes but with the inputs that go into a decision. These are called cues and will be described later. The importance at this point is that the inputs differ in a number of qualitative ways from each other, even though they are believed to be quantitatively related to decision outcomes. In contrast, inputs in SDS and STS are preferences for the decision alternatives themselves. Second, the decision alternatives vary along a univariate continuum (such as levels of danger, quality of job applicants, or projected dollar value of an asset) and the levels of the alternatives

or outcomes may be continuous across the range of decision
alternatives. For SDS or STS, decision alternatives are
limited to two or a very small number. Finally, the model
to be presented here is an adaptation of an individual
decision model and, therefore, has many parallel processes
at the individual team member level with respect to the
decision making process. SDS and STS, by contrast, are not
analogs of decision making at the individual level. To
introduce the model, we shall first describe the individual
model from which it was derived.

An individual decision-making model. The model adapted to
team decision making is the lens model first developed by
Brunswik in the 1940s and 1950s (Brunswik, 1940; 1943; 1955;
1956). Individuals' decisions are seen to result from the
evaluation of a finite set of cues or predictors. Two sets
of decision rules are applied to the cues. Each set is
represented by a function (typically linear) that best fits
the cues to the decision (Y). In Figure 1, the shaded
region represents one function and the unshaded another.
The symbols, r_i' and r_i, represent the weights multiplied by
the cue value X_i on the i cue in the respective functions
with respect to its contribution to the final decision. The
shaded portion represents the "correct" or "true" cue-to-
criterion functional relationship and the unshaded the best
estimate of the decision maker's own decision function based
upon the decisions he or she makes when presented with a
number of sets of cues. The equation for the shaded portion
is often described as the ecological validity. With the
ecological validity in place, a decision maker's choices
(decisions/judgments) can be compared with choices that
should have been made if the decision maker had followed the
a priori model.

The model outlined in Figure 1 is based on the assumption
that individuals are rational decision makers who obtain
information on the relevant set of cues for any particular
decision, assign weights to the cues and reach decisions.
Under ideal conditions, decisions can be shown to follow the
model quite closely. However, under most conditions, the
gap between the correct model on the left and actual
decisions on the right is not small. A large body of
research exists that offers explanations for the gap between
the two models (e.g., Kahneman & Tversky, 1973; March &
Simon, 1958).

A Team Lens Model. When organizations are faced with
complex decision problems, a common way to simplify them is
to assign the complex decision to a staff of experts who

"Correct" Decision and
Cue "Correct Cue"
Validities

Person's Decision and
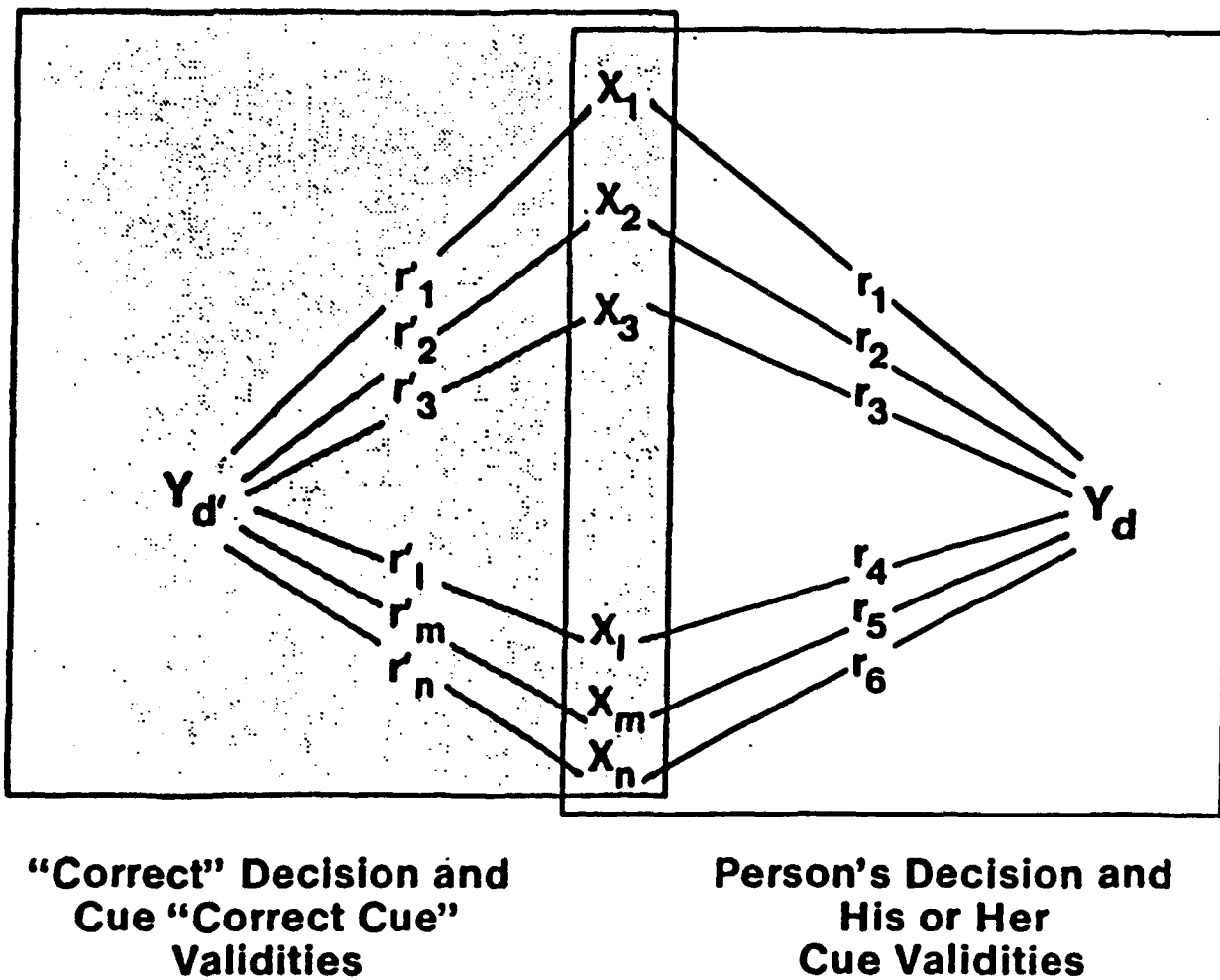His or Her
Cue Validities

Figure 1. Brunswik lens model of decision making.

divide the larger problem along lines of their expertise
(Brehmer & Hagafors, 1986). Brehmer and Hagafors' (1986)
model, presented in Figure 2, is a special case of such a
situation in which the complex problem represented by the
column of cues is subdivided into sets of two cues assigned
to each of three individuals.

In an illustrative laboratory study, Brehmer and Hagafors
(1986) varied the validity of the initial set of cues and
the validity of the subordinates' judgments. They found
that if one subordinate made less valid judgments than the
other two, leaders, when presented with the cues themselves
rather than the subordinate's judgment, underutilized cues
that were the responsibility of the less reliable
subordinate. An interesting general finding was the fact
that it was not easy for leaders to learn how to make good
decisions under conditions where the staff provided
specialty-based opinions derived from only a subset of the
total data.

A Distributed Expertise Team Decision Making Model. By
their own admission, Brehmer and Hagafors' (1986) model
represented a very limited team adaptation of the social
judgment model of individual decision making. Our goal was
to build upon a lens type model both by modifying the basic
structure in ways that represent team decision making when
expertise is distributed across members and by extending the
team processes from learning to performance. To describe
the team model, we first begin with characteristics of
hierarchical teams and build on a decision making structure.

Figure 3 illustrates a hierarchical decision making team
with four members. Such teams have three primary
characteristics - hierarchy (unequal status among members),
distributed expertise, and a task, the outcome of which is a
decision from the team. In the case illustrated, each of
the subordinate members makes a judgment (j_A - j_C), and
subordinates' judgments are passed to the leader who makes a
decision (d_D). Typically, the leader's decision represents
the decision of the team.

Expertise is the allocation of critical information (cues)
regarding the decision to individuals in the team and
knowledge how that information should be used to reach
decisions. Figure 3 illustrates allocation. A cue vector,
X, contains elements (X_i) that represent specific values on
the dimension. In Figure 3, Person A is an expert in the
knowledge domain represented by X_1 and X_2, Person B by X_2, X_3,
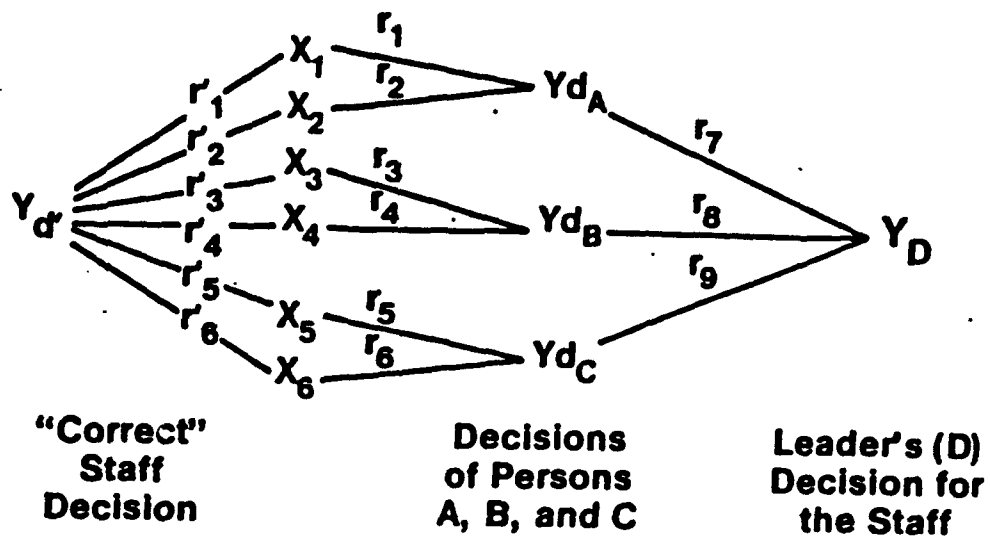and X_4, Person C by X_5 and X_6, and the leader by X_2 and X_5.

Figure 2. Brehmer and Hagafors' model of staff decision making.
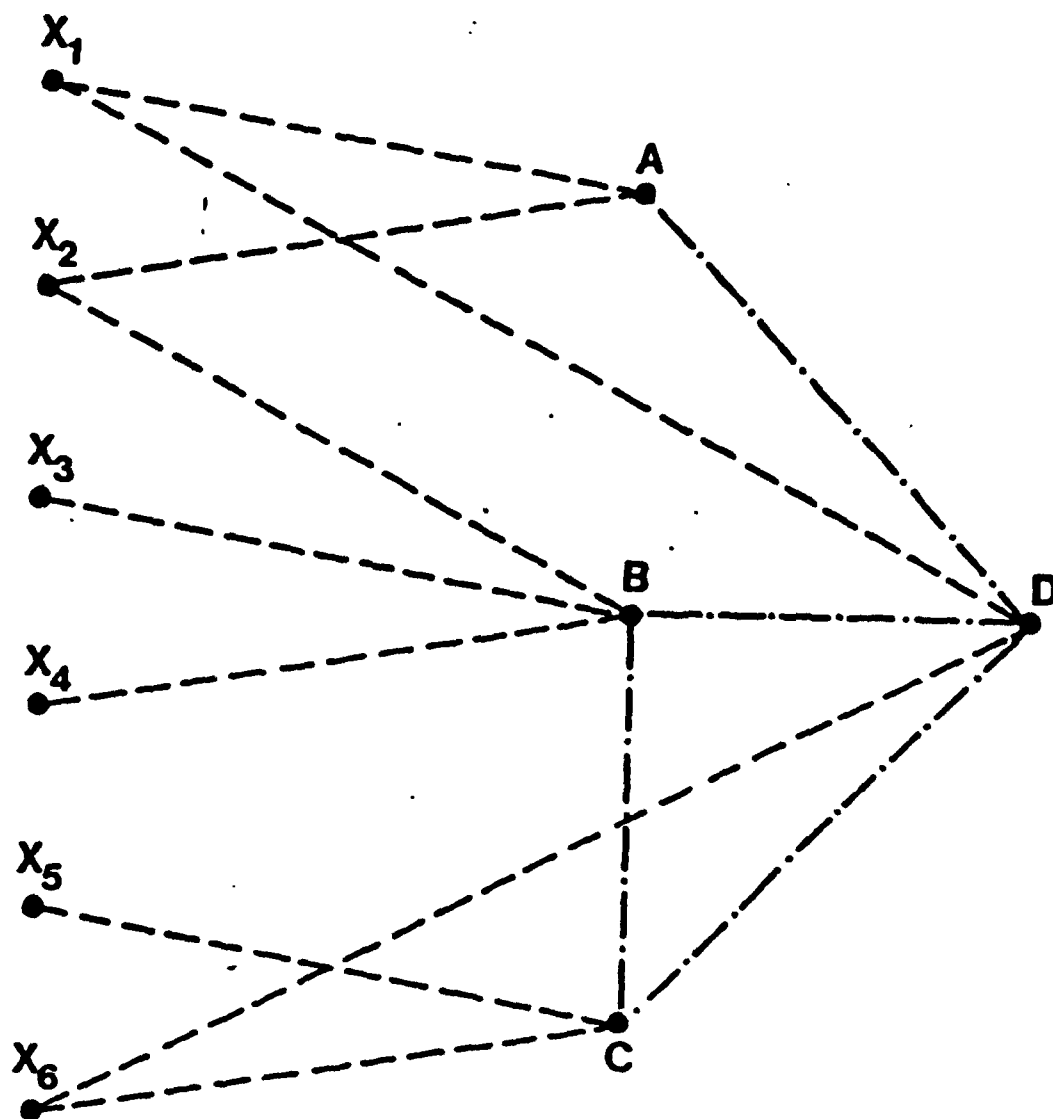
Figure 3. Hierarchical decision making in a four-person team.

Note that, although the distribution of expertise is represented by the way in which information is allocated to every member of the group, it is not necessary that each vector of information be available to only one of the team members.

Finally, Figure 3 illustrates one other important feature of teams--a communication structure (see dotted lines). By definition, communication structures exist among persons. The communication structure illustrated is a simple one where subordinates communicate only with their leader and vice versa. Obviously, many other forms are possible in h'erarchical teams. The combination of the communication system with the expertise system provides the structure within a team for potential access to information by each team member.

With Figure 3, we have incorporated distributed expertise into a team hierarchy in such a way as to provide a structure for describing how information becomes available to team members for making decisions. The availability of information relevant to a team decision represents a necessary but not sufficient condition for reaching a decision. The remainder of the process involves the decision itself. In particular, the concern is with how the information is used by the team to reach a decision and with the quality of the decision. In order to evaluate the latter, decision making research typically has used decisions for which the quality of decisions can be evaluated against criteria established a priori.

Figure 4 introduces the decision process to the combination of the hierarchy. As was the case in the earlier illustrations, six dimensions of information are used to reach a decision (X_1 - X_6). Working left from the X_is, the a priori or "correct" decision is represented by Y_d'. Analogous to the individual decision model discussed earlier, the Y_d' is the "correct" decision to which the team's decision can be compared.

The right hand portion of Figure 4 represents decisions made in the team. As illustrated, there are judgments and decisions. The judgments are made by Persons A, B, and C, symbolized by Y_{jA}, X_{jB}, and Y_{jC}. Each team member's judgment can be represented or captured by regressing the individual's judgment on the cues presented to him or her. The decision is that of the leader (Y_{dD}). This decision has the potential for being a little more involved than subordinate judgments. One way for the leader to make a
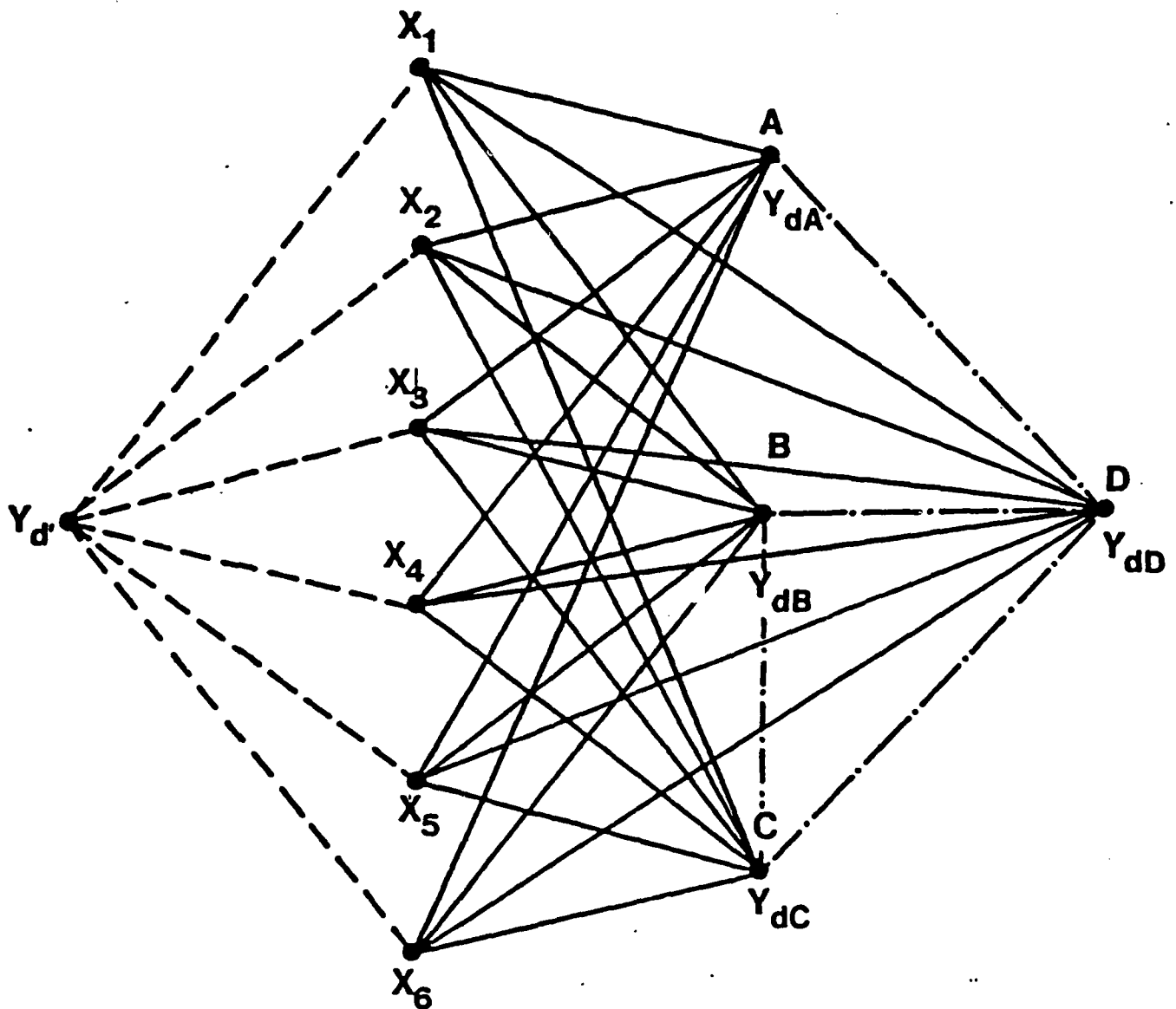
Figure 4. Hierarchical decision making in a four-person team with distributed expertise.

decision is exactly the same as the way subordinates make judgments. That is to say, the leader can base his or her decision upon a linear combination of the six cues. However, unlike the subordinates, in the configuration illustrated in Figure 4, the leader has access to the judgments of each of the subordinates in addition to access to cue information. Thus, the subordinate judgments are analogous to cue dimensions for a decision by the leader based on three cues. Therefore, the leader's decision can also be modeled as a function of the three subordinates' judgments.

This completes the conceptual framework of our model of decision making in hierarchical teams with distributed expertise. The discussion provides a descriptive model of a structure for decision-making teams with distributive expertise. Establishing this descriptive model is important, because it serves as the base from which we can develop a normative theory of effective team decision making. That is, once we know what these teams must do from an information processing perspective, we can then suggest variables that would appear to be most critical in understanding why such teams do and do not make good decisions. A theory of team decision making effectiveness is developed in our next section.

The Multi-Level Theory of Hierarchical Team Decision-Making

Figure 5 depicts the inputs and outputs of the decision making process at various levels. At the decision level, the decision object itself generates attribute scores on various dimensions (a_1 through a_6). This information is then processed at the individual level by staff members, who then generate judgments that are sent on to the leader. The leader interacts dyadically with each staff member, and this interaction leads to the leader forming an opinion about the validity of the staff members's judgment. This belief held by the leader is viewed as the weight the leader assigns to the staff member's judgment.

With this as an overview, three general propositions are made regarding team decision-making effectiveness. These are:

> Proposition 1: Team decision making accuracy (TDMA) is determined by constructs that occur at one of four levels. These are the team level, the dyadic level, the individual level, and the decision level.
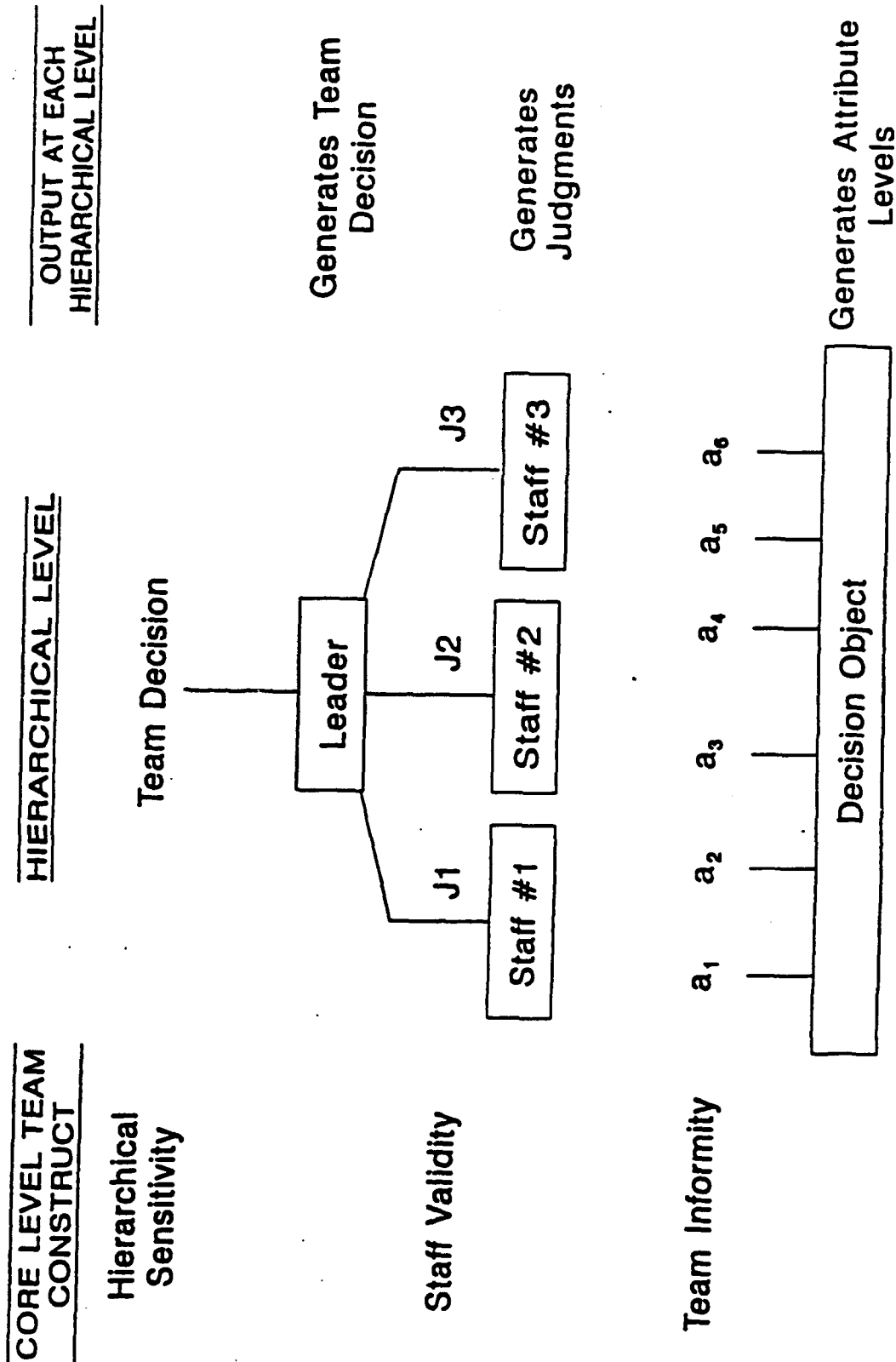
Figure 5. Multiple levels involved in team decision making and the corresponding core level constructs

Proposition 2: Three core, team-level constructs, team informity, staff validity and hierarchical sensitivity (to be described later) directly impact TDMA, and each of these has a lower level analog (i.e., an analog at the dyadic, individual or decision level).

Proposition 3: The effects of "non-core" variables (i.e., lower level constructs, and non-core, team related constructs) on TDMA are mediated by the core constructs.

Figure 6 illustrates team decision effectiveness as mediated by the three core constructs and their analogues at levels of analyses below that of the team. The outer ring of the figure contains classes of variables believed to affect team decision making effectiveness through their effects on core constructs. The descriptive categories on the outer ring were chosen to represent the three primary domains of variables--physical-task, social and individual--represented by McGrath's (1976) model of organizational behavior. The remainder of our discussion describes the theory in greater detail.

Core Team-Level Constructs. The first critical team-level construct is team informity. Team informity is the degree to which the team as a whole is apprised of all the relevant cue values associated with the dimensions on which the decisions are based, on average. Thus, team informity is primarily a product of factors that occur at the decision level, but it is itself a team-level construct. A team that is highly informed knows a great deal about the decision objects on average; a team that is poorly informed knows little of the relevant information regarding the decision objects on average.

Informity can be expressed as:

$$I_j = \sum_{i=1}^{k} a_{ij} \, n_j \, / k \; a_k \, n_j \qquad [1]$$

where a_{ij} is the number of attributes, a, known on Decision Object i by Team j, a_k is the total number of attributes that could possibly be known on Decision Object i, n_j is the number of members in Team j, and k equals the number of decisions made by the team.

TEAM
DECISION-
MAKING
EFFECTIVENESS
(TDME)

Core Team Level
Constructs

Core Non-Team
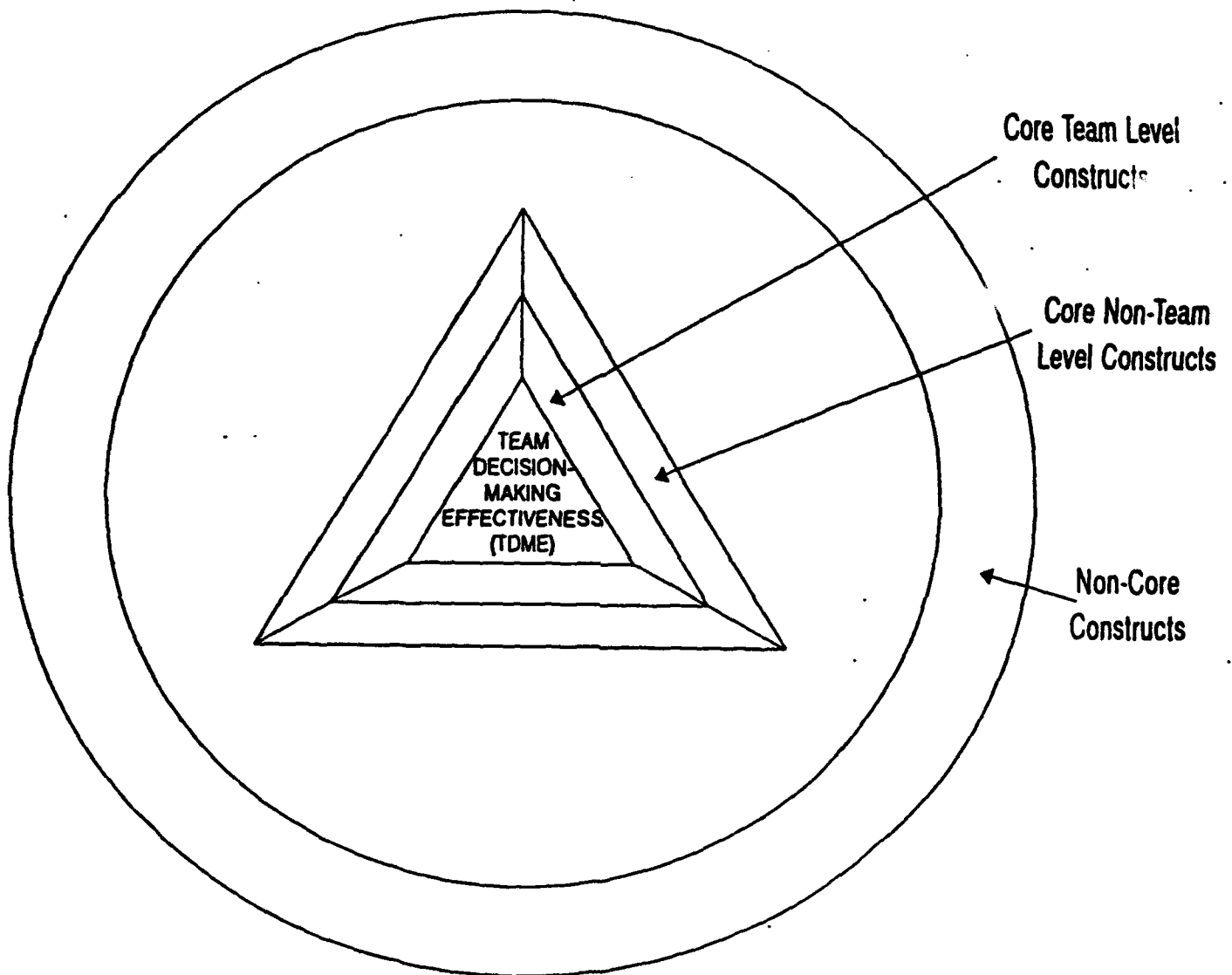Level Constructs

Non-Core
Constructs

Figure 6. Overview of the Multi-level Theory of hierarchical team decision making.

Figure 5, for example, shows a situation with six relevant dimensions where the decision object can be apprised by three different staff members and the leader. In this situation, the maximum amount of information the team can possess for any one decision is 24, where each of the three staff members has information on each of the six dimensions and so does the leader. The minimum level of team informity is 0, where no one has any information on any of the decision objects, and the maximum is 1.0, where every team member has every piece of information on every decision.

The first sub-proposition in MLT dealing with team informity states:

> Proposition 2a: All else constant, TDMA will be higher for well-informed teams than poorly informed teams.

The second important team-level construct is staff validity. Staff validity is the degree to which the team as a whole has lower level members who can accurately judge the decision object from the available cues. Thus, staff validity is primarily a product of factors that occur at the individual-level but is itself a team-level construct. A team that is high in staff validity generates judgments or opinions about the decision object that predict the true state; a team that is low in staff validity has lower level members whose judgments or opinions fail to predict the true state.

Figure 5, shows a situation in which the three staff members each generate one opinion about the decision object based upon their knowledge of the cues. At the staff level, judgments are being made, not decisions. Thus, the predictability of the criterion (regardless of the direction of relationship) is the key to staff validity. That is, it is the magnitude, rather than the sign of the relationship that is critical. For example, a perfect inverse relationship between a staff member's opinion and the criterion would be of great value to a leader who recognized that the member was perfectly predictable in the opposite direction. Indeed, one of the interesting, non-intuitive aspects of team decision-making made clear by the theory is that a staff that might make terrible decisions as individuals, can still generate highly effective judgments. As long as their judgments predict the proper decision well, it does not matter that they are biased if the leader properly corrects for the bias when using their judgments.

The absolute value of the correlation between the staff member's judgments and the correct decision gives an

indication of the degree to which his or her opinion is
useful to the upper-level decision-maker. By definition,
the average correlation across all team members is staff
validity.

That is:

$$SV = \sum_{m=1}^{n} |r_{mj}| \ / \ n_j \qquad [2]$$

where r_{mj} is the predictive validity of team member m on
Team j, and n_j is the number of staff in Team j.

The maximum level of predictability generated by an
individual staff member's judgment, expressed as a
correlation, is 1.0 (or -1.0). At the team level, the
highest possible staff validity (i.e, average absolute value
of the validities) is 1.0 (it occurs when the true score can
be perfectly predicted from each of the team members). The
lowest possible staff validity would be zero. This leads to
a second MLT sub-proposition:

> <u>Proposition 2b</u>: All else constant, TDMA will be higher
> for teams that are high in staff validity than teams
> that are low in staff validity.

The third critical team-level construct is <u>hierarchical
sensitivity</u>. Hierarchical sensitivity is defined as the
degree to which the team leader effectively weighs staff
members' judgments in arriving at the team's decision.
Thus, hierarchical sensitivity is primarily a product of
factors that occur at the dyadic-level, but it is itself a
team-level construct. A team that is high in hierarchical
sensitivity has a leader who uses the best possible weight
for each staff member's opinions when combining these to
arrive at the team's decision. A team that is low in
hierarchical sensitivity has a leader whose weighting system
deviates substantially from the optimum.

Returning again to Figure 5, it shows a situation in which
the leader receives three judgments from his or her staff
members. The best possible set of weights that can be
applied to staff judgments would be given by the b weights
associated with the ordinary least squares regression of the
three judgments made by the staff on the true score
criterion. Any deviation from this set of weights by the
leader would result in a performance decrement relative to
the optimum. The actual weights that the leader applies to
the staff member judgments, on the other hand, are given by

the b weights associated with the ordinary least squares regression of the staff member judgments on the leader's decision. Hierarchical sensitivity can therefore be conceptualized as the average difference, expressed as an absolute value, between the b weight for each staff member's judgment in predicting the criterion, and the b weight for each staff member's judgment in predicting the team decision made by the leader. That is:

$$HS = \sum_{m=1}^{n} |B_{mt} - B_{ml}| / n_j \qquad [3]$$

where B_{mt} is the b weight for Team Member m's judgment in predicting the "true score" on the decision object, B_{ml} is the b weight for team member m's judgment in predicting the leaders decision, and n_j is the number of staff members (hence hierarchical dyads) in the team. The maximum sensitivity for any dyad is thus zero. The maximum hierarchical sensitivity for the team as a whole is also zero.

> The third major sub-proposition of MLT is then:
> <u>Proposition 2c</u>: All else constant, TDMA will be higher for teams characterized by high hierarchical sensitivity relative to teams that are low in hierarchical sensitivity.

<u>Core Lower-Level Constructs</u>. As should be apparent from the above description, each team level core construct is an average of phenomena that occur at levels below the team level. That is, informity at the team level is the average of how much information a team had on each decision object. Staff validity at the team level is the average of the predictive validity of each team member. Hierarchical sensitivity at the team level is the average of the sensitivity displayed for each of the hierarchical dyads. This implies that there is a lower level analog of each of the team-level core constructs in MLT.

The lower level analog of team informity is referred to as <u>decision informity</u>. Decision informity is a construct that occurs at the decision level, and is simply the amount of information the team had on any one specific decision object that was encountered. The lower level analog of staff validity is <u>individual validity</u>. As the name implies, individual validity is a construct that occurs at the

individual level and is simply the predictive validity of any one staff member. The lower level analog of hierarchical sensitivity is dyadic sensitivity. Dyadic sensitivity is the degree of similarity between the weight given to a specific staff member by the leader, and the weight given to the same specific staff member by the OLS regression used to predict the criterion. Figure 7 reflects the three lower level core constructs and their relationship to the core team level constructs and overall team decision making effectiveness.

One of the important implications of adding these constructs to the theory is that it illustrates that much of the research on TDMA needs to occur at sub-team levels. Research needs to focus not just on TDMA per se, but on lower level constructs central to TDMA because of their relationship to core team level constructs.

Non-Core Constructs. All constructs other than the six listed above are labeled "non-core constructs." Included in the latter set are constructs that occur at lower levels (decision level, individual level, and dyadic level) as well as at the team level. To describe the domain of non-core variables, we have adapted a framework developed by McGrath (1976). According to our position, core constructs mediate the relationship of non-core constructs to team decision-making effectiveness, but it is hypothesized that particular non-core constructs are more likely to be mediated by some core constructs than by others. Figure 8 imposes the categorical scheme for the non-core constructs onto the theory as presented in Figure 7.

It is proposed that:

> Proposition 4a: Team Informity is determined primarily by constructs that would be classified as originating in the physical/technical environment (e.g., ambiguity in cues or time pressure), the task (e.g., centralized or decentralized information structures), and the behavior setting (e.g., physical proximity of staff members).

> Proposition 4b: Staff Validity is primarily a factor of variables that would be classified within the person (e.g., cognitive ability, job knowledge, experience, aggressiveness), the task (e.g., the range of information available to each staff position), and roles (e.g., the amount of information informally shared between staff members).
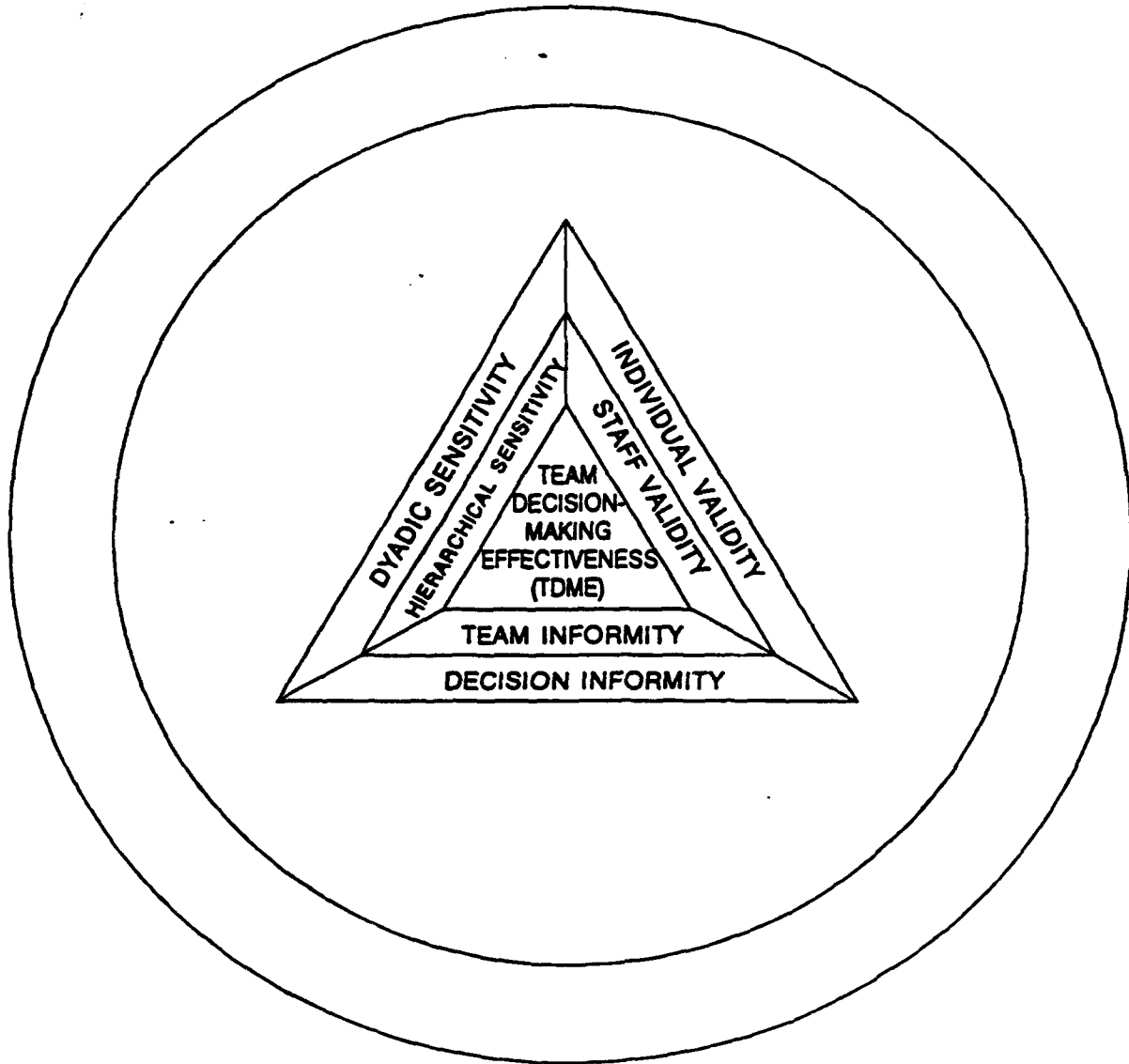
Figure 7. Core non-team level constructs and their relationship to the core team-level constructs and team decision making effectiveness.
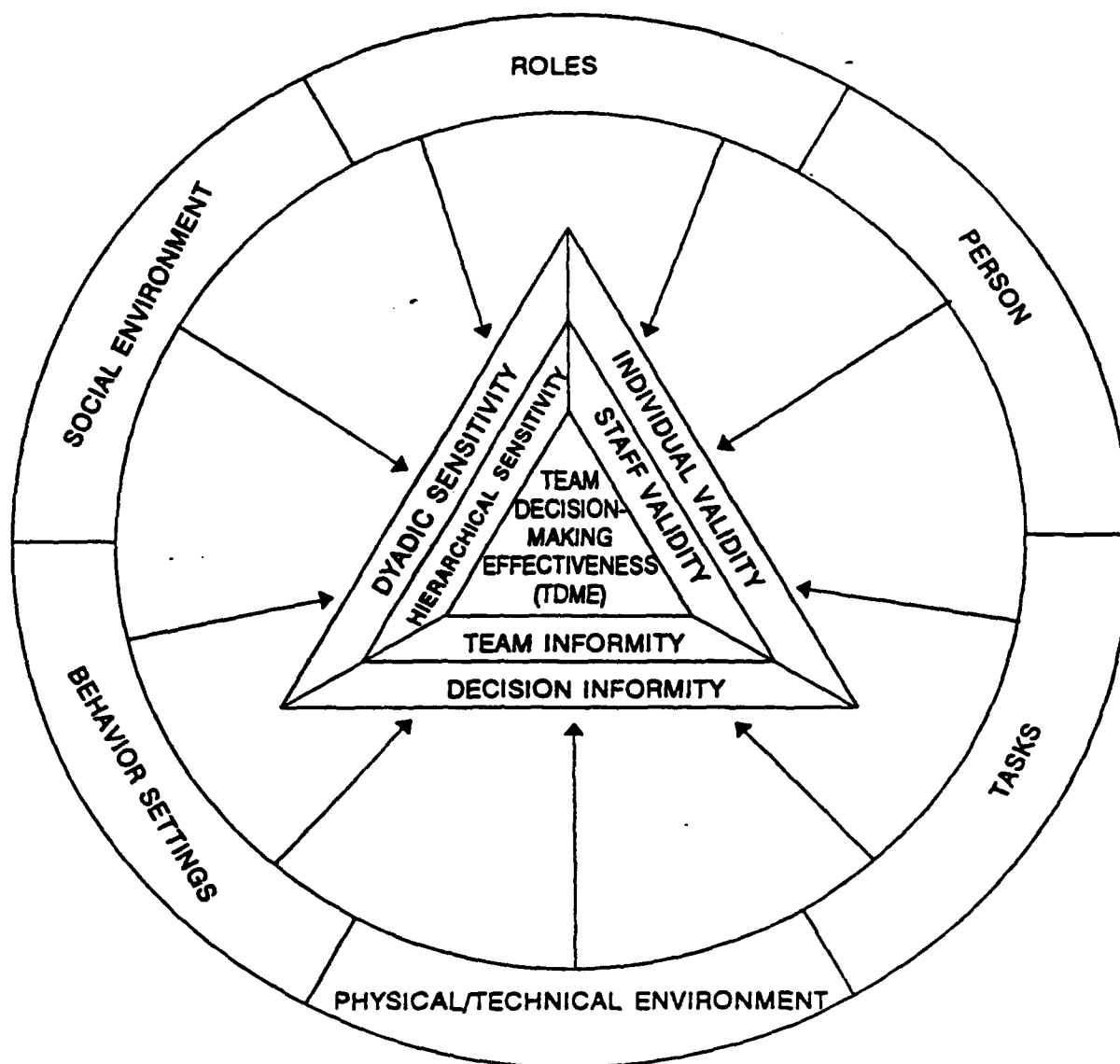
Figure 8. The effects of various classes of non-core variables on the core variables.

Proposition 4c: Hierarchical sensitivity will be
influenced primarily by constructs that originate from
the social system (e.g., group familiarity, stability
or cohesion), roles (e.g., role redundancy, role
conflict or role ambiguity) and behavior settings
(e.g., physical proximity between leaders and staff).

As a potential theory of decision accuracy, the theory has
several desirable characteristics. First, it is relatively
parsimonious. It isolates three primary core, team-level
factors that lead to decision accuracy. Second, it
incorporates multiple levels of analyses by recognizing that
activities in teams are occurring at different levels and
that important outcomes occur within decisions, within
persons, within dyads and within the team as a whole.
Analytic procedures have been adopted to deal with the
multilevel nature of team decision making (see Hollenbeck,
Ilgen, & Sego, in press). Also, while maintaining
parsimony, the theory gains comprehensiveness by proposing a
six-fold taxonomic framework within which common team
constructs are located and linked to the core constructs.

Finally, by isolating the three core team level constructs,
the theory decomposes overall team decision making
performance into three sub-components. This is advantageous
for a number of reasons. First, it allows one to
differentiate teams that may be similar in overall
achievement, based upon their decision making performance at
the sub-component level. For example, two teams that
display the same level of overall decision accuracy may
achieve their results differently. One team might do so
because of unusually high staff validity that is combined
with merely average levels of hierarchical sensitivity.
Another team may achieve the same results because of
unusually high hierarchical sensitivity that is combined
with only average levels of staff validity. In short, it
recognizes equifinality.

In addition, recognizing performance at the sub-component
level allows one to detect the effects of variables that
have multiple but conflicting effects on overall TDMA. For
example, if two staff members are put in a position of role
conflict such conflict might have deleterious affects on
each persons validity, yet enhance the leaders hierarchical
sensitivity. If the positive and negative influences of
this variable cancel each other out, then one who looks only
at overall TDMA could easily overlook the effects of this
variable. On the other hand, if the dual effects of this
variable were understood, then subsequent efforts could be

directed at developing specific kinds of role conflict that aid the leader, yet do not hamper staff validity.

Methods for Studying Team Decision Making

Team Decision Making Simulation

A great deal of the time and effort devoted to this project involved the development of a team decision making simulation exercise. The simulation was designed for four person teams whose members interact with each other through a computer medium. Teams are presented with problems that involve gathering information on dimensions called attributes, processing that information and making a decision based on the information. Team members are assigned roles that vary along two dimensions, status and expertise. With respect to status, they are either assigned to the role of leader or staff. Staff members gather information and pass along their judgments to the leader, but the leader is primarily responsible for the decision of the team. Expertise, on the other hand, is varied by training members so that they possess knowledge about the meaning of particular pieces of information and have the ability to access or measure that information. With these two structural differences, the teams interact electronically and then reach decisions within the framework of the problems with which they are presented. For a complete description of the exercise, called TIDE^2 (Team Interactive Decision Exercise for Teams Incorporating Distributed Expertise), see Hollenbeck, Sego, Ilgen, & Major (1991).

To illustrate the simulation, we shall briefly describe a configuration of it that we have used for several studies. However, it should be pointed out that the software for the exercise was developed to allow for a great deal of flexibility regarding the content and structure of the problem. Teams can be studied that deal with a wide variety of issues, such as purchasing a piece of equipment or admitting a patient in an emergency room. To change the nature of the problem requires only changing a few key parameters in the program.

For research on this project, teams simulated the task of monitoring the airspace surrounding an aircraft carrier. The team leader was located on the carrier, and his or her staff members were on a cruiser, in an aircraft within the area (AWACs), and on land (Coastal Air Defense, CAD). The decision task was that of deciding how to address aircraft

that flew through the airspace. Possible responses to them varied from the least aggressive stance of simply ignoring the aircraft to the most aggressive one of engaging the aircraft in combat.

When an aircraft came into the team's airspace, the job of the team members was to work together to learn as much about the aircraft as possible and then reach a decision about how to respond to it. The aircraft had nine characteristics. These were such things as speed, altitude, direction, the nature of its radar (IFF), and its location with respect to corridors reserved for civilian aircraft. Through initial training, team members learned aircraft characteristics, how to measure these characteristics, and rules for making decisions regarding responses to the aircraft. A sample rule would be that aircraft that are low, small and coming at you are likely to be dangerous. In almost all cases, the rules represented interactions among aircraft characteristics and not main effects. That is to say, single cues rarely possessed sufficient information to make a reasoned judgement.

Staff member and leader expertise were varied by controlling the information about the aircraft to which a person had access and by training regarding rules for engaging the aircraft. Access meant that information about any particular characteristic of the aircraft could only be measured by one or a small subset of persons on the team. Likewise, no person knew all combination rules. Furthermore, although each team member knew one or more rule about the way in which a subset of characteristics or cues combined to influence how the team should respond, no one team member was able to measure all pieces of information important for any particular rule. Thus, it was necessary for team members to communicate among themselves to get the information to reach decisions.

Decisions made in the teams were of two types. First, staff members reached their own decision regarding the status of the aircraft. They then passed this decision on to the person in the carrier position, the leader. Thus, leaders typically had the benefit of knowing how each of their staff members viewed the aircraft prior to reaching their own decision about the aircraft. The leaders' decision served as that of the teams'. That is, when the leader made a decision, that decision was recorded as the decision for the team.

As the exercises were designed for this series of research, all team members were informed of the judgments of all

members regarding the aircraft and of their leaders'
decision. This feedback occurred immediately following the
time when the leader reached a decision. For each aircraft,
it was possible to determine what a correct decision should
have been, given the rules for the problem. Thus, the
feedback following a decision not only reported the decision
reached by the leader and the staff members but also the
accuracy of the decision. Finally, since quite a few
aircraft were presented to each team at any one session,
cumulative feedback over trials was also frequently
presented to the teams. Although it is possible with the
simulation to suppress feedback.

Since all interactions among team members occur
electronically, the simulation software records all these
behaviors as well as the time intervals between responses.
A vast amount of data is collected on each team,
necessitating reducing the data to variables that are
meaningful for studying team behavior. Although all raw
data are preserved, a number of summary variables have been
constructed. Early pilot work with the simulation assessed
the construct validity of key variables of interest in the
research so that decisions regarding the use of the
simulation for future research would have some basis to
judge the quality of a number of variables. Hollenbeck,
Sego, Ilgen, Major, Hedlund, & Phillips (in press). In
particular, the quality of measures of stress, team decision
making accuracy, and other measures of team processes is
evaluated and reported in that report.

Repeated Measures Regression and Team Data

The need for appropriate statistical power poses limitations
on team research. Given the difficulty of assembling and
observing teams and the fact that researchers are often
interested in assessing and analyzing data collected on
several variables, it is usually very difficult to obtain a
sufficiently large number of observations to meet the
standards for even modest levels of statistical power. This
problem is particularly severe with longitudinal research
observing behavior in teams over time; the ability to obtain
sufficient numbers of teams for between teams analyses
quickly becomes prohibitive even with a relatively small
number of variables.

Although team research often is limited to a small number of
teams, frequently multiple observations are made on these
teams, and often these the variables of interest occur at a
level below that of the team. Consider the case of 20 four
person teams, each with a leader and three subordinates, in

which the investigator is concerned about the nature task coordination between leaders and their team members. Frequently investigators have analyzed data like this at the team level by calculating a mean score for each team leader based on the average relationship between the team's leader and his or her followers. However, the coordination of interest occurs at the level of the dyad, not that of the team. Therefore, we have argued that the analysis should fit the level of the construct. This argument is not new. Graen and his colleagues (Dansereau, Graen, & Haga, 1975; Dansereau, Alutto, & Yammarino, 1984) have made the same point for years regarding leader behavior. However, although a method has been developed to deal with dyads by some of Graen's students, the arguments for its use have been primarily conceptual.

In an article by Hollenbeck, Ilgen and Sego (in press), a case is developed for using repeated measures regression for analyzing team data. Two advantages of the statistical procedure are stressed. The first of these is that many of the relationships of interest in team research do not occur at the team level. The dyadic one just mentioned is one of them. There are many more. Repeated measures regression allows the researcher to first select the level of analysis most appropriate for the research question and then analyze the data at that level. Second, shifting to appropriate levels allows for increases in statistical power when the appropriate levels are below that of the team. For example, in the example above, the sample size for dyadic relationships would be 60 rather than 20 if team level analyses were conducted. Hollenbeck et al., (in press) describes the method and computations needed to use it in team research. Although the manuscript adds nothing new with regard to the technique over what Cohen and Cohen presented in 1983, it does introduce the method to team research. Most all of the analyses for the team data collected in the laboratory have used repeated measures regression as the primary analytic method.

Tests of the Theory

All the advantages of the theory hinge on demonstrating empirical support. The remainder of this report presents two studies that address propositions from the theory. Three objectives guided the design of the research. The first, and primary, of these was to use a research paradigm that would allow us to evaluate the ability of the theoretical constructs proposed in the theory to account for team decision making accuracy. The second was to address issues in team decision making that were important for the

operation of real teams in ongoing organizations. Finally, to the extent possible, we wanted to meet boundary conditions that have been identified as most critical for teams in operational settings.

The first study involved teams that work together over extended periods of time. Half of the teams were composed of persons who had known each other for quite some time before participating in the team. The other half of the teams had members who were strangers at the beginning of the research, although they did meet together to work on the task for relatively long time periods spread out over several weeks. In addition, we introduced turnover and team member replacement into the team experience to study a very common problem faced by many work teams, that of maintaining teams over time in the face of team member turnover with replacement.

In order to provide the opportunity for extended interactions, familiarity, and attrition, only a few groups could be run under these conditions. The cost of this was low statistical power, a common problem in team research. To address this limitation, a second study was run with far fewer sessions per team but with far more teams. Use of two studies created the opportunity to observe the ability of the theoretical predictions to replicate under different conditions. It was felt that the combination of the two studies provided the opportunity to meet several important boundary conditions and still attain reasonable confidence in the inferences drawn from the research.

Study 1

Team and small group research has been criticized for ignoring the team's history--a potentially critical feature in real life settings (cf., McGrath & Rotchford, 1983). Past and anticipated future experiences interact with present conditions to influence responses of team members. Yet, a vast majority of the existing research data is based on behavior in ad hoc teams or groups that are assembled for one time only. This study was undertaken to evaluate the theory under conditions that varied three critical variables in teams that are linked to the temporal conditions.

The first variable of interest was that of team member familiarity. In contrast to ad hoc research groups whose members are often chosen randomly to control for systematic effects of unmanipulated variables, teams in real life environments are composed of people who get to know each other over time. Because member familiarity is a social

construct, it was predicted that its effect on the quality of decisions in decision making teams would be strongest on hierarchical sensitivity (see Figure 7). That is, all else equal, leaders of familiar teams, in comparison to leaders of unfamiliar ones, should be better able to weigh differentially the contributions of their staff.

The second temporally-related variable manipulated was that of the stability of team membership. Over the life of many teams, particularly those in work organizations, members drop out and others are added as the team is maintained but its membership changes. Work with teams of scientists with innovative tasks implies that the lack of replacement over time may lead to a decreased openness to new ideas (Katz, 1982). Others have found that production teams increase in productivity when old members are replaced with new (Insko, Gilmore, Moehle, Lipsitz, & Drenan, 1982; Moreland & Levine, 1989). Whether such an increase in performance will occur in decision making teams is less clear. Given that effective decision making depends on both the leader learning how to evaluate the decisions of his or her team members (hierarchical sensitivity) and the members' ability to make good decisions (staff validity), if new members are drawn with replacement from a population of persons with equal ability, we would expect an initial drop in the quality of team decisions. This drop would be attributable to the need for the leader to get to know the member and the time that it takes the member to learn the decision making task.

Finally, interaction over time leads inevitably to greater experience with the task, which served as the third independent variable. All else equal, one might expect that increased experience leads to enhanced capacity to use information to arrive at sound recommendations. This should also affect all three core variables in the theory, but the greatest impact should be on staff validity and hierarchical sensitivity.

Method

Subjects. Research participants were 84 undergraduate students at a large midwestern university. All were paid an hourly rate for their participation ($5.00). In addition, all had the opportunity to earn additional bonuses paid to their teams and based upon team performance. The top performing team in each condition earned an additional $80.00, the next best team earned $40.00, and the third best team earned $20.00.

Task Overview. Research participants worked at team-based version of the TIDE^2 simulation task. In this particular study, TIDE^2 was programmed to simulate a naval command and control scenario. Participants were assigned roles in four-person hierarchical teams with a leader and three members. These roles consisted of the commanding officer (CO) on an aircraft carrier (i.e., "Carrier"), who was the team leader, and three COs of different air patrol units--one in the air (an AWACs), one on water (an Aegis Cruiser) and one on land (Coastal Air Defense or CAD). Each team member was trained so as to possess unique expertise regarding one aspect of the air patrol task.

The team's task was to monitor the airspace surrounding the Carrier. Teams performed this task for approximately three hours per night, one night a week for six weeks. When any aircraft came into the airspace, each team member needed to gather some information about particular attributes of the aircraft (e.g., its speed, direction, angle, range, size, etc.), and then arrive at a judgment regarding the appropriate response to make toward the aircraft in the airspace. Judgments and decisions were rendered on a seven point continuum that varied in aggressiveness from Ignore (the lowest level of aggressiveness, to Defend (the most aggressive response). Intermediate anchors on this scale in increasing levels of aggressiveness included Review (2), Monitor (3), Warn (4), Ready (5), and Lock-on (6).

While teams were monitoring traffic, they were stationed at a computer that was networked with the computers of other team members. All operations transpired over the network. A clock on the screen counted down the time before the team needed to make a decision. The target began to beep when there was 30 seconds remaining, thus giving a clear impression that the time available for making a decision was running out. Recommended actions from team members were forwarded to the leader, who considered them along with the information on the attributes that he or she had obtained. He or she then made a final action decision for the team. Table 1 shows the nine dimensions on which aircraft varied, the ranges of their scale values, and a description of each dimension. Table 2 shows the different areas of expertise for each staff member. Note that no team member is an expert on all nine attributes, and thus the team is characterized by what we referred to earlier as "distributed expertise."

Table 1

The Dimensions, Scales and Ranges for Decision Stimuli

	Degree of Threat		
	Non-Threatening	Somewhat Threatening	Very Threatening
Speed	100-275mph	325-500mph	600-800mph
Altitude	35,000-27,000ft	23,000-17,000ft	13,000-5,000ft
Size	65-43mtr	37-23mtr	17-10mtr
Angle	+15 to +8dgs	+3 to -3dgs	-8 to -15dgs
IFF	.2 to .6Mhz	.9 to 1.1Mhz	1.4 to 1.8Mhz
Direction	30 to 22dgs	18 to 12dgs	08 to 00dgs
Corridor St	0 to 8mi	12 to 18mi	22 to 30mi
Radar Type	Class 1 & 2	Class 5	Class 8 & 9
Range	200 to 110mi	90 to 60mi	40 to 1mi

Table 2

The Areas of Expertise for Each Team Member

Carrier:

>   Altitude; IFF; Radar Type;

>   Other Staff Members' Expertise

>   Angle--Range Combination Rule

AWACs:

>   Speed; Altitude; Size; Angle; IFF

>   Speed--Direction Combination Rule

Cruiser:

>   Angle; IFF; Direction; Corridor Status; Radar Type

>   Altitude--Corridor Status Combination Rule

Coastal Air Defense:

>   Corridor Status; Radar Type; Range; Speed;

>   Altitude Size--Radar Type Combination Rule

Task Training. There were two primary components to the training for the simulation. First, people needed to learn the mechanics of gathering and sharing information about an aircraft in the airspace. Information about the mechanics of the task was presented to team members first on a videotape on the basic task conditions. A second component of the training was an instruction booklet. Following training all were then required to take an objective test on the contents of the booklet and obtain a passing score before advancing to the final phase of the training. The last stage of this part of the training was a sample problem presented to the team at their terminals and performed while the experimenter was in the room to guide them through the exercise and answer questions.

The second part of the training dealt with learning the roles. Role information unique to each position was presented in the written booklet. As is shown in Table 2, each team member had expertise that was unique to his or her role. That expertise was taught in the training session and came in three forms: (a) the ability to measure attributes of the aircraft, (b) the ability to translate raw data on aircraft attributes into judgments regarding how threatening the aircraft was on that attribute and (c) the knowledge of rules.

For example, although all team members knew that military aircraft were more threatening than non-military aircraft, only two people in the team could actually measure this attribute (i.e., Attribute #5). These two team members were also the only ones trained in how to translate raw data on the "IFF" scale (i.e., 0.0 to 1.6 Mhz) into judgments about threat (i.e., non-threatening, somewhat threatening or very threatening). In addition, each team member memorized one of the four combination rules (e.g., one member must memorize how speed and direction go together). Thus, at least one member of every team was an expert on one of the combination rules.

Like all the other team members, the leader memorized one combination rule. Relative to his or her teammates, however, the Carrier position could only measure a relatively small number of aircraft attributes. The distinctive competency of the Carrier was that this person was an expert in terms of knowing the expertise of all the other team members.

One last feature about the team's task was interdependency. Although, four of the five rules for determining actual threat involved combinations of cues, no one team member

could measure both of the necessary components of any combination rule. That is, if one member could assess "speed," that person was unable to measure "direction," the attribute that combined with speed to determine the actual threat level. Therefore, to fully appreciate the nature of the aircraft, team members had to share information and expertise with each other. Someone had to inform the person who could measure speed, the direction of the aircraft (information) and had to help that person translate raw values on direction (expressed in degrees) into levels of threat.

Team Performance. The team's decision was made by the leader. Once made, the leader's response was compared to the correct decision. This correct decision was based on translating the rules into a linear combination of the attributes and applying the equation to the attribute values of the stimulus aircraft. The leader chose one of the seven alternatives described above (i.e., Ignore, Warn, Defend, etc.) and performance was based on the degree to which the leader's decision matched the correct decision (operationalized as the absolute value of the difference). Five alternatives were possible for the seven point scale. The performance scale and the verbal anchors associated with it were: Hit = no difference, Near Miss = a decision one off from the correct decision; Miss = 2 off; Incident = 3 off; and Disaster = a difference of 4 or more. Following the leader's decision, each person in the team received performance feedback on his or her monitor that told the team's performance on the trial, the decisions of each of the team members, and the cumulative performance of the team expressed as a sum of its performance on all trials since beginning the session. Finally, a projection of what the team's total score would be at the end of the experiment if the team continued to perform at the same level was also provided. The feedback screen was presented for 15 seconds. After 15 seconds, a new aircraft entered the region, the feedback screen was removed, and, the next trial began.

Research Design. There were three non-core variables of interest in Study 1, and these were configured in a 2 X 2 X 4 design. There were two levels of Familiarity (Familiar versus Unfamiliar Teams), two levels of Attrition (Attrition versus No Attrition), and four levels of Task Experience. The latter was a "within subjects" variable (i.e., each team was observed at each level of experience).

Variables. Familiarity was manipulated during the recruitment of research participants. The members of approximately half of the teams (n = 11) knew all team

members prior to participating in the research. They were recruited through advertisements that specifically requested that all four members apply together and that they be persons who had known each other for some time. Most members of familiar teams turned out to be roommates and/or persons who lived in close proximity to each other in the dorms, in fraternities, or shared a house off campus.

Persons for the unfamiliar teams (n = 10) were recruited individually from a large lecture section of an introductory management class. These participants telephoned the research laboratory and were assigned to teams by the researchers. The sole criterion for composing the unfamiliar teams was that the members not know each other prior to the experiment, nor expect to interact with each other after the experiment.

Attrition was manipulated halfway through the experiment (i.e., after the second experimental session). At this time, approximately half the teams had one member removed and replaced by another person. In each case, someone from one familiar team was switched to an unfamiliar team and vice versa. The selection of the person who was removed (and thus, the role that person played in the team) was randomly determined.[1] Only staff members were removed. Team leaders always stayed with their initial team.

Experience was operationalized as the amount of time people had worked on the TIDE[2] simulation, and this was scaled in terms of the session number (i.e., 1 through 4). By the end of the experiment, each team had 12 hours of experience and had made 127 decisions.

Team Performance was the an index of the accuracy of the team's decision and was described earlier. In addition, the core variables of the theory, hierarchical sensitivity, staff validity, and team informity were constructed from team member responses as per the formulas also described earlier.

Data Analysis and Statistical Power. Data analysis proceeded in four stages and was guided by the theory as depicted in Figure 8. We started at the center of the model for the first stage and examined the effect of the core-team level variables on team decision accuracy. That is, we assessed whether teams that were high in team informity, staff validity and hierarchical sensitivity outperformed teams that were low on these characteristics.

In the second stage of the analysis, we moved to the outside of the model, and examined the effects of the of non-core variables on team decision accuracy. That is, we assessed whether teams that were initially familiar, had stable membership, and were high in experience outperformed teams that were unfamiliar, unstable and low in experience.

In the third stage of the analysis we performed the first half of the analyses to test for the mediational effects of the core constructs. To accomplish this, we examined the degree to which the non-core constructs affected the lower level analogs of the core team level constructs. That is, we tested the relationship between familiarity, attrition and experience on decision informity, individual validity, and dyadic sensitivity.

Finally, in the fourth and final stage, we tested to see if the relationship between the non-core constructs and team decision accuracy was attenuated when one controlled for team level core constructs. That is, we tested to see if any effects discovered in the second stage of the analysis described above dissipate if one controls for the effects discovered in the first stage. If the effects of familiarity, attrition, and experience on team decision accuracy are substantially attenuated by controlling for team informity, staff validity, and hierarchical sensitivity, then we conclude that the core team level variables mediate the effects of the non-core variables.

Repeated measures regression was used to analyze this data (Cohen & Cohen, 1983). Hollenbeck, Ilgen, and Sego (in press) show how this technique can be applied to longitudinal studies of teams and discuss several of its advantages in terms of statistical power and the ability to test mediation. This technique first divides the overall variance in the dependent variable into within and between portions, and then systematically analyzes each portion separately. Enhanced statistical power relative to pure between subjects designs is derived by obtaining multiple observations per team. In addition, power is enhanced by removing irrelevant sources of variance from the F ratio denominator (e.g., between team variance when examining within team variance and vice versa) when making inference tests.

The statistical power for the analyses described above varies at different stages. The reason for this is that the number of observations available differs for different dependent variables. For example, the lowest level of power is associated with the first stage of the analyses, where

there were only 21 observations (one per team). Because of the causal proximity between these variables and team decision accuracy, however, one would expect larger effect sizes, which enhances the power of the analysis at this stage. For example, if the core team level constructs and their interactions explain 45% of the variance in team decision accuracy, then the statistical power to detect a semi-partial R^2 for any individual effect of .15 at the .05 level of is between .70 and .75.

In the second stage, the non-core variables are the predictors of the more distal team performance criterion. Here one would expect much smaller effect sizes. However, for these analyses, the number of observations is larger because team experience is a predictor. The inclusion of team experience opens up the design to within team variation, and hence multiple observations per team. Since there are four levels of experience, this means that there are a total of 84 observations (21 teams X 4 levels of experience). If the non-core variables can account for as much as 12% of the variance in decision accuracy, then the regression associated with this test has .80 statistical power at the .05 probability level.

In the third stage of the analysis, we examine the effects of the non-core variables on the lower level analogs of the team level core constructs and have very high power. The power comes from a large number of observations when the dependent variables are below the team level. Thus, when individual validity of each staff member is the dependent variable, there are 63 persons (21 teams X 3 staff members per team). In addition, since these 63 persons are evaluated at four different levels of experience, this provides a total of 252 observations (63 persons X 4 levels of experience). There are also 252 observations available when dyadic sensitivity is the dependent variable. That is, there are 3 hierarchical dyads in each group, there are 21 groups, and each dyad can be assessed at 4 different levels of experience. Finally, when decision informity is the dependent variable, the number of observations expands to 2,667. This number reflects the fact that at the decision level, there are 127 decisions for each of the 21 teams. Clearly, the level of statistical power for all of the analyses reported at the third stage is high even for trivially small effect sizes.

Finally, in the last stage, the power is similar to that associated with Stage 2, since there are again 84 observations. However, because these analyses include the

three core team level variables as predictors, and these variables are likely to have larger effect sizes relative to the non-core variables used in Stage 2, the power is slightly higher than .80 here.

Results

Descriptive Statistics. Table 3 shows the means, standard deviations and intercorrelations for the all the variables examined in Study 1 when the number of observations is 84. Recall that this n = 84 database is only relevant for the analyses discussed in Stages 2 and 4. The four analogous correlation matrices for the databases where n = 21, n = 256, and n = 2,667 are available from the first author.

Effects of the Core Variables on Performance. Table 4 shows the results of regressing overall team decision accuracy on the three core team level constructs and their interactions. As expected, there was a strong relationship between the core constructs and team performance. Despite adjusting these results for shrinkage due to the small sample size, 49% of the variance in decision accuracy was explained by the three core variables and their interactions.

Almost all of this variance was attributable to the effect of team informity and the interaction between staff validity and hierarchical sensitivity. The regression weight for team informity indicated that decisions were more accurate for teams that were high in team informity. A plot of the interaction indicated that teams that were both high in hierarchical sensitivity and staff validity performed much better than those who were low on either one or both. Thus, a team that is high in staff validity does not necessarily perform well if their leader is low in sensitivity. Similarly, a highly sensitive leader is of little value to a team if matched with a poor staff. A leader with a poor staff member can weight that staff member zero (and hence be sensitive) yet be no closer to where he or she needs to be to make an accurate decision.

To further explore the combined effects of the three core constructs, we isolated teams within sessions that were either high on all three characteristics or low on all three and compared their performance both overall and in terms in avoiding severely bad outcomes (i.e., disasters). These results are plotted in Figure 9. In terms of overall performance across all sessions with all teams, the mean level of accuracy was .84 with a standard deviation .13. Teams that were high on all three core characteristics had a mean of .75 compared to a mean of 1.06 for teams low on all

Table 3

Descriptive Statistics for Study 1

| Variable | Mean | S.D. | Intercorrelations | | | | | | |
			(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Decision Accuracy	0.84	.20	---						
(2) Team Informity	0.80	.09	-.62*	---					
(3) Staff Validity	.63	.15	-.38*	.50*	---				
(4) Hierarchical Sensitivity	.17	.09	.27*	-.28*	-.32*	---			
(5) Experience	2.50	.73	-.30*	.68*	.18	-.29*	---		
(6) Familiarity	0.48	.50	.14	.01	.05	-.17	.00	---	
(7) Attrition	0.51	.50	-.13	.11	.05	.13	.00	.00	---

Table 4

The Effects of the Three Core Team Level Constructs on Team Decision Accuracy[a]

Dependent Variable = Team Decision Accuracy

Hierarchical Step	Independent Variables	Total R^2	Total R^2 Adjusted	Incremental Adjusted R^2
(1)	Hierarchical Sensitivity (HS)	.05	.00	.00
(2)	Staff Validity (SV)	.10	.00	.00
(3)	Team Informity (TI)	.34*	.22*	.22*
(4)	HS X SV	.54*	.43*	.21*
(5)	HS X TI	.57*	.43*	.00
(6)	TI X SV	.64	.49*	.06

[a] n = 21 (one observation per team)

* $p < .05$

Study 1
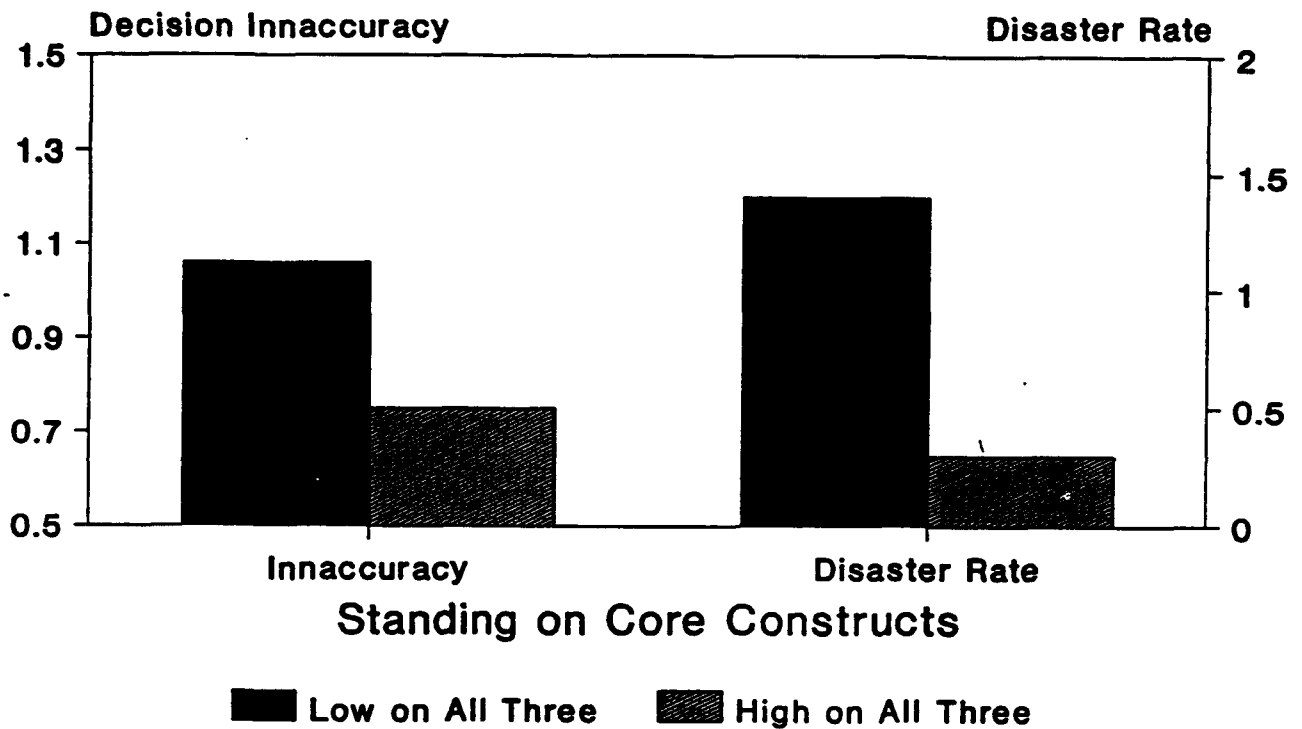# Combined Effects for Core Constructs

Figure 9. The combined effects of the core constructs on overall accuracy and disaster rates in Study 1.

characteristics. Since low scores reflect higher accuracy
(a perfect score equals zero), this means that the teams
that were high on all three core characteristics scored
roughly two standard deviation units above those low on all
three characteristics.

In terms of avoiding severely bad outcomes, we computed the
probability of a team experiencing a disaster (i.e., the
teams decision was off by four or more points). In general,
although disasters were relatively rarely occurring events,
as shown in Figure 9, they were five times more likely to
occur in teams that were low on all three characteristics
(1.4%) relative to teams that were high on all three
characteristics (0.3%).

The Effects of the Non-Core Variables on Performance. Table
5 shows the results of regressing team decision accuracy on
the three non-core variables and their interactions using
repeated measures regression. Because this analysis
includes task experience (a within team factor) as an
independent variable, there are 84 observations.

The majority of the variance in team decision making
accuracy (TDMA) occurred within, rather than across teams.
That is, of the total variance, 62% was attributable to
within team variance, whereas only 38% was attributable to
between team factors. Task experience had a significant
effect on decision accuracy and accounted for a
statistically significant 14% of the within team variation.
As one would expect, the direction of this effect indicated
that teams' decisions became more accurate as they gained
experience.

The between groups variables (attrition, familiarity and
their interaction) accounted for 13% of the between group
variance (which was 5% of the total variance) and this was
not statistically significant. It should be noted that the
degrees of freedom for the denominator associated with the
between group factors is based on the n = 21 rather than the
n = 84 (see Cohen & Cohen, 1983, p. 444-448 for a discussion
of this issue); hence there is less statistical power
associated with inference tests involving only between team
factors.

The Effects of the Non-Core Variables on Core Variables.
Tables 6, 7 and 8 show the results of regressing the three
non-core variables and their interactions on the lower level
analogs of the core team level variables. Since there are
four observations for each team, and since there are three
staff members for each team and three hierarchical dyads for

Table 5

The Effects of the Non-Core Variables on Team Decision Accuracy[a]

Dependent Variable = Team Decision Accuracy

Hierarchical Step	Independent Variables	Total R^2	Incremental R^2	Incremental Variance Accounted Within	Incremental Variance Accounted Between
(1)	Experience (E)	.09*	.09*	.14*	
(2)	Familiarity (F)	.11*	.02		.05
(3)	Attrition (A)	.13*	.02		.05
(4)	F X E	.14*	.01	.01	
(5)	A X E	.15*	.01	.00	
(6)	F X A	.16*	.01		.03

[a] n = 84 (four observations per team)

* $p < .05$

Table 6

The Effects of the Non-Core Variables on Core Variables--Dyadic Sensitivity[a]

Dependent Variable = Dyadic Sensitivity

Hierarchical Step	Independent Variables	Total R^2	Incremental R^2	Incremental Variance Accounted Within	Incremental Variance Accounted Between
(1)	Experience (E)	.03*	.03*	.04*	
(2)	Familiarity (F)	.04*	.01		.03
(3)	Attrition (A)	.05*	.01		.03
(4)	F X E	.05*	.00	.00	
(5)	A X E	.08*	.03*	.04*	
(6)	F X A	.08*	.00		.00

[a] n = 252 (3 observations per team for four time periods)

* p < .05

Table 7

The Effects of the Non-Core Variables on Core Variables--Individual Validity[a]

Dependent Variable = Individual Validity

Hierarchical Step	Independent Variables	Total R^2	Incremental R^2	Incremental Variance Accounted Within	Incremental Variance Accounted Between
(1)	Experience (E)	.00	.00	.00	
(2)	Familiarity (F)	.00	.00		.00
(3)	Attrition (A)	.00	.00		.00
(4)	F X E	.03*	.03*	.05*	
(5)	A X E	.06*	.03*	.05*	
(6)	F X A	.09*	.03*		.08*

[a] n = 252 (3 observations per team for four time periods)

* $p < .05$

Table 8

The Effects of the Non-Core Variables on Core Variables--Decision Informity[a]

Dependent Variable = Decision Informity

Hierarchical Step	Independent Variables	Total R^2	Incremental R^2	Incremental Variance Accounted Within	Incremental Variance Accounted Between
(1)	Experience (E)	.26*	.26*	.26*	
(2)	Familiarity (F)	.26*	.00		.00
(3)	Attrition (A)	.26*	.00		.00
(4)	F X E	.28*	.02*	.02*	
(5)	A X E	.29*	.01*	.01*	
(6)	F X A	.29*	.00		.00

---

[a] n = 2,667 (127 observations per 21 teams)

* p < .05

each team, this means that there are 252 observations when individual validity or dyadic sensitivity is the criterion. When decision informity is the criterion (and thus the analysis is at the decision level), there are 127 decisions for each of the 21 teams. This means that there are 2,667 observations for this dependent variable.

Turning first to dyadic sensitivity, examination of the total variance revealed that 70% of this was attributable to within dyad factors, whereas 30% was attributable to between dyad differences. Examining the independent variables indicated that there were statistically significant effects for experience which explained 4% of the within team variance, and an experience by attrition interaction, which also explained 4% of this variance. Follow-up analyses of plotted mean differences indicated that, in general, dyadic sensitivity increased over time. However, this increase was much more pronounced for dyads within teams that did not experience attrition relative to dyads in unstable teams. Changing staff members disrupted the ability of the leader to develop an effective weighting scheme for his or her staff.

The between dyad effects for attrition, familiarity and their interaction accounted for 6% of this variance but this was not statistically significant. Again, the degrees of freedom in the denominator for the between dyad factors, based on n = 63 (i.e., 3 dyads per 21 teams) is less than the same degrees of freedom for the within dyad factor where n = 256 (i.e., 63 dyads for each of four time periods), and this has the predictable effects on statistical power.

Table 7 shows the results of trying to predict individual validity from the non-core constructs. Examination of this total variance indicated that only 60% of the variance was due to within person factors, whereas 40% was due to between person factors. Within individuals, the results indicated that 10% of this variance was explained by interactions of experience with familiarity and stability. When plotted, these interactions revealed that experience had a positive influence on the validity of individual staff members, but that this effect was stronger for unfamiliar teams and teams that maintained stable membership. Staff members of unfamiliar teams started out with lower validities than staff members of familiar teams but eventually surpassed them by the end of the fourth session. In terms of attrition, staff members in stable teams generally reached an asymptote by the second session of the experiment (validity of .66 on average) and maintained this over the remaining two sessions. Staff members in teams that

encountered attrition reached the same asymptote by the second session, but then their validities decreased after attrition occurred.

In terms of between person variation, despite the smaller degrees of freedom associated with these factors, there was a statistically significant interaction between familiarity and attrition, which accounted for 8% of the between group variation. This interaction, when plotted, indicated that attrition was more disruptive to staff members in familiar teams, than it was to staff members in unfamiliar teams.

Table 8 shows the results of regressing decision informity on the non-core constructs. Examination of this total variance indicated that 87% of it was attributable to within team factors, whereas only 13% was due to between team factors. There was a very strong effect for task experience. Over time, all teams became much better informed on the decision objects. Given the large number of observations for within decision factors, almost any increment in R^2 would be significant in this regression. The largest effect size for the interactions was associated with the familiarity by experience interaction which, when plotted, suggested that the relationship between experience and decision informity was slightly stronger for unfamiliar teams than familiar teams. In the early sessions, unfamiliar teams were somewhat less informed than familiar teams, but this difference was eliminated over time.

In summary, the results of this stage of the analysis suggested that there were significant associations between the non-core variables and the core variables. For the most part, teams and team members improved on all three of the core level variables over time, although the gains achieved were more pronounced for some of the core constructs (e.g., team informity) than others (dyadic sensitivity). Also, the benefits of increased experience for some of the core constructs (e.g., individual validity and dyadic sensitivity) were somewhat contingent upon familiarity and/or stability of team membership. Although, in general, team members validity increased with experience, this relationship was attenuated for familiar teams and unstable teams. With respect to dyadic sensitivity, the beneficial effects of experience were more pronounced for unfamiliar teams relative to familiar teams. Also, with respect to dyadic sensitivity, familiarity held some advantages for teams that were stable, but not for teams that experienced attrition.

The Mediating Influence of the Core Level Variables. In the final stage of the analysis we tested to see if the effect of the non-core variables were transmitted through the core constructs. Since only one of the non-core constructs, that is experience, had a direct effect on decision accuracy, this was the only variable tested. To test for mediation, we performed a hierarchical regression where decision accuracy was the criterion, and the core constructs were entered first as predictor variables. Then we entered experience and compared the partialed effect size to the unpartialed effect size.

The first part of this analysis may seem similar to the analysis shown in Table 4, but there is a major difference between these two sets of analyses. The results in Table 4 are based on 21 observations where each team was assigned one score for each of the three core constructs that was obtained by taking their average across the different levels of experience. Hence the 21 observations are independent. The results in Table 9 are based on 84 observations, where each team is given a score on each of the core constructs at each level of experience. Thus, the 84 observations captured in this analysis are not truly independent. Table 4 provides the more accurate assessment of the effect of the core constructs on team level decision accuracy. The primary focus of Table 9, however is on the partialled effect for experience, not the effects of the core constructs.

When one controls for the three core level team constructs, the impact of experience, while still statistically significant, is reduced substantially. Whereas experience formerly accounted for 9% of the variance in decision accuracy, after partialing the core constructs, this effect size decreases substantially to 3%--a 67% reduction in variance explained. The core constructs mediate much, but not all of the effects of experience.

Discussion of Study 1

In general, the results of Study 1 were supportive or partially supportive of the major propositions emanating from the Multi-Level Theory (MLT) of team decision-making. Our first proposition was that team decision making accuracy (a team level construct) was affected by factors that occurred at three lower levels of analysis (i.e., the decision-level, the individual level, and the dyadic level). At the decision level, for example, the degree to which the team was informed on each individual decision they made was related to how effectively they performed overall as a team.

Table 9

The Effects of the Non-Core Variables on Team Decision

Accuracy Controlling for the Core Variables[a]

Dependent Variable = Team Decision Accuracy

Hierarchical Step	Independent Variables	Total R^2	Incremental R^2
(1)	Hierarchical Sensitivity (HS)	.08*	.08*
(2)	Staff Validity (SV)	.20*	.12*
(3)	Team Informity (TI)	.41*	.21*
(4)	HS X SV	.43*	.02*
(5)	Experience	.46*	.03*

[a] n = 84 (4 observations per 21 teams)

* $p < .05$

Factors that originated at the individual and dyadic-levels actually interacted to determine decision-making effectiveness. Teams that had individual staff members who made highly valid recommendations outperformed those with members low in validity, but only when paired in a hierarchical dyad where the leader was sensitive in terms of weighting each staff members judgment appropriately.

The second proposition, dealing with the impact of the three core-level team constructs was also supported. These constructs explained almost half of the variation in team decision making accuracy--even after controlling for inflation due to the small sample size. The practical significance of the effect of the three variables taken as a whole was evident when comparing teams that were high on all three core characteristics to teams that were low. Teams high on all three core characteristics performed roughly two standard deviation units above teams who were low on all three, and the disaster rate for teams that were low on all three variables was five times the disaster rate for teams that were high on all three.

The third proposition, that the core-variables mediate the relationship between non-core variables and decision accuracy was only partially supported when the non-core variables were familiarity, attrition and experience. Of these three, only experience had a direct effect on decision accuracy. Although the strength of the task experience effect on performance was greatly attenuated when the core variables were controlled (a 67% reduction), this variable still had a small direct effect that was not attributable to the core constructs.

In the introduction we noted that decomposing overall accuracy into the three core constructs allows one to identify variables that have multiple but conflicting effects on overall accuracy. For example, in this study, there were both advantages and disadvantages to familiarity. On the positive side, familiar teams seemed to be better coordinated, and therefore showed higher levels of team informity and staff validity, at least during the first half of the experiment. On the other hand, attrition was much more debilitating to familiar teams relative to unfamiliar teams and, over time the staff validity of unfamiliar teams exceeded that of familiar teams. When taken altogether, familiarity had no affect on overall team decision making accuracy, yet one would be mistaken to conclude that these teams do not differ in terms of important sub-components of overall team performance.

Finally, we will note that one of the interesting results that emerged from Study 1 dealt with the differences between the three core constructs in terms of the amount of variation in each that was attributable to within versus between team factors. Team informity was a variable that, in this study, varied primarily within teams (only 13% of the total variance was attributable to between team factors). This is not all that surprising for this task because measuring information and shipping it around the system was probably the easiest part of the task to learn. Therefore, most of the variation was attributable to all the teams getting more efficient at this over time.

Using this information to make accurate judgments (staff validity) and to differentially weight various recommendations (hierarchical sensitivity) were the more complex parts of this task to learn. This is reflected in the fact that more of the variance in these two variables (30-40%) was attributable to stable differences between teams. Even here, however, there was substantial within team variation, and this could be explained by differences in experience and interactions between experience, familiarity and attrition. Indeed, one of the strengths of Study 1 was its ability to closely monitor these different types of teams perform and evolve over a six week time span that included over 120 decision opportunities.

On the other hand, given the time and resource constraints of the research team, this kind of long-term, longitudinal scrutiny could only be achieved at the expense of dealing with a relatively small number of teams. Obviously, one would need to try to replicate some of these major findings in a study that involved a larger number of teams, and this was exactly our motivation to conduct Study 2.

Study 2

Study 2 was designed as a replication and extension of Study 1. It was a replication in two senses. First, it allowed for a second examination of the effects of the core team level constructs on overall decision-making accuracy. Second, it allowed for a test of the core variables mediation influence in transmitting the effects of non-core variables on team performance.

Study 2 extended Study 1 in two ways. First, whereas Study 1 studied a small number of teams (21) that made a large number of decisions (127), Study 2 studied a much larger number of teams (102) that made a smaller number of decisions (24). Thus, whereas Study 1 derived statistical

power from a large number of observations, Study 2 derived its statistical power from a larger number of teams.

Second, Study 2 examined a different set of non-core variables. One of the primary variables examined is Study 2 is informational redundancy. Informational redundancy reflects the degree to which there is overlap in expertise among the staff members. Typically, informational redundancy is considered a positive aspect within groups because it provides a system of checks and balances on team members. Since no one member is completely responsible for a given task, intentionally designing redundancy into the system provides a back-up system in case one member makes a mistake.

On the other hand, redundancy could potentially be a negative factor in team decision making, under some circumstances. For example, team members may be less careful if they know someone is backing them up. In addition, poor coordination among redundant staff could lead to a situation where each person assumes that the other person is covering their area of joint expertise. If left unchecked, assigning two people responsibility for one task might lead to no one performing it all. Finally, if redundant information is viewed as shared information, there is some evidence to imply that team members may spend more time communicating about common information at the expense of sharing the unique information each has to offer. Stasser and Titus (1985) found that groups spent disproportionately more time discussing topics on which they all shared the same information than on ones for which group members did not all possess the information. Such action inhibited information exchange. Within MLT, informational redundancy would be considered a characteristic of the "Role Environment," and hence we would predict that the effect of this variable on team performance would be mediated by dyadic sensitivity or individual validity.

A second primary variable of interest to Study 2 is staff member competence. Clearly, it is in every groups interest to maximize the competence of its members, and within MLT, the reason for this is the effect that competence has on Staff Validity. However, our primary interest in Study 2 is to examine (a) the size of the impact that one poorly performing member can have on a four person team, and (b) the degree to which this impact can be attenuated by informational redundancy. One might speculate that informational redundancy attenuates the negative effect of having an incompetent member on one's staff because it

allows the leader and other members of the team to work around the incompetent member.

Finally, the last variable of interest in Study 2 is team cohesiveness. One reason for including cohesiveness was to include a construct similar to familiarity in Study 1. Another, and more critical reason to include the construct was to determine its ability to buffer the effects of an incompetent team member. Working around an incompetent member calls for (a) a quick identification and diagnosis of the problem with a particular member, and (b) an ability and willingness on the part of others in the team to go above and beyond their normal roles. One might predict that teams that were low in cohesiveness would be both slow to identify a member who was having difficulty, and be less willing to pick up the additional responsibilities required to "cover" for this individual.

Method

Subjects. Research participants were 372 undergraduate students at a large midwestern university. These individuals, along with 36 confederates, whose roles will be described later, were constituted into 102 separate four-person teams. All were paid for their participation in a manner similar to that described in Study 1.

Task Overview. Research participants worked at team-based version of the TIDE[2] simulation task which was described above for Study 1.

Research Design. Study 2 employed a 3 X 2 X C design where information redundancy and member competence were manipulated, and team cohesiveness was measured as a continuous variable. Unlike Study 1, this design was a between subject design with one observation per team.

Manipulations and Measures. Information redundancy was manipulated using the Measure feature of TIDE[2]. Specifically, we created three different conditions where team members had varied capacity to directly measure the nine potential attributes of the aircraft that were being monitored. In the low redundancy condition, each of three staff members could directly assess only three attributes. Since there were nine attributes in total and three staff members on each team, this meant that there was no redundancy on any attribute. In the medium redundancy condition, each staff member could measure five of the nine attributes. This meant that there was 66% redundancy among

the staff members, in that six of the nine attributes could be measured by more than one person, whereas the remaining three attributes could only be measured by one staff member (this was the setting applied in Study 1). In the high redundancy condition each staff member could assess 7 attributes directly creating 100% redundancy; every attribute could be assessed by at least two (if not three) staff members.

Member competence was manipulated through the use of a confederate, who was a trained undergraduate student paid by the research team. The confederate was always assigned the role of the Coastal Air Defense (CAD) position. Confederates were compliant team members who did all that was asked of them (i.e., they answered any direct queries sent their way), however their recommendations to the Carrier (i.e., Ignore, Warn, Defend, etc.) were random responses. They were also unable to translate any raw data on attributes into subjective levels of threat if they were asked to do so by other team members via the text message system. Each confederate had a list indicating their pre-determined responses to each of the trials, and a script for answering any of a variety of text messages that might require a response on their part.

Team cohesiveness was not manipulated, but measured with a seven-item scale containing items such as "I liked my team a lot," "My teammates were very cooperative," "All of us on the team seemed to see things the same way" and "Some team members seemed to be working primarily for themselves and not for the team" (reverse coded). Each team members response to each of the seven items was treated as an empirical indicator of the team's cohesiveness, and the 28 separate indicators were combined to form the overall measure. The scale showed an acceptable degree of internal consistency, with a coefficient alpha estimate of reliability of .75.

Data Analysis. The same four-stage data analytic scheme was used in Study 2 as in Study 1. Specifically, in the first stage of the analysis, we tested for the effects of the three core constructs and their interactions on overall team decision making accuracy. In the second stage, we tested the for the effects of the non-core constructs on overall decision making accuracy. In the third stage, we performed the fist half of the mediational analyses to see if the non-core constructs were related to the core constructs. Then in the final stage, we tested to see if the effect of the non-core constructs on decision accuracy was eliminated after controlling for the core constructs. Since all

variables in Study 2 were between team variables, repeated measures regression was not used.

Results

Descriptive Statistics. Table 10 shows the means, standard deviations and intercorrelations for the all the variables examined in Study 2.

Effects of the Core Variables on Performance. Table 11 shows the results of regressing overall team decision accuracy on the three core team level constructs and their interactions. There was a strong relationship between the core constructs and team performance, in that 27% of the variance in this criterion was accounted for by these three variables and their interactions. The strongest effect in Study 2 was for Staff Validity, which explained 18% of the variance by itself. The effects for Hierarchical Sensitivity and Team Informity were weaker. The direction of these main effects was as expected, in that teams that were high on all three of these constructs outperformed teams that were low.

The interaction between Hierarchical Sensitivity and Staff Validity found in Study 1 was replicated, although the direction of this affect was subtlety different. Whereas in Study 1, teams that were high on both Hierarchical Sensitivity and Staff Validity stood out from the other groups in terms of their high performance, in Study 2, teams that were low on both of these constructs stood out for their low performance.

As in Study 1, to further explore the combined effects of the three core constructs, we isolated teams that were either high on all three characteristics or low on all three and compared their performance both overall and in terms in avoiding severely bad outcomes (i.e., disasters). These results are plotted in Figure 10. In terms of overall performance across all sessions with all teams, the mean level of accuracy was .95 with a standard deviation .20. Teams that were high on all three core characteristics had a mean of .80 compared to a mean of 1.12 for teams low on all characteristics. Since low scores reflect higher accuracy (a perfect score equals zero), this means that the teams that were high on all three core characteristics scored roughly one and a half standard deviation units above those low on all three characteristics.

In terms of avoiding severely bad outcomes, we computed the probability of a team experiencing a disaster (i.e., the

Table 10

<u>Descriptive Statistics for Study 2</u>

Variable	Mean	S.D.	Intercorrelations						
			(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Decision Accuracy	0.95	.20	---						
(2) Team Informity	.57	.86	-.19*	---					
(3) Staff Validity	.59	.13	-.44*	.25*	---				
(4) Hierarchical Sensitivity	.18	.10	.08	-.11	-.21*	---			
(5) Redundancy	.01	.46	-.06	.72*	.24*	-.18	---		
(6) Cohesion	3.58	.31	-.38*	.13	.42*	.04	.05	---	
(7) Staff Competence	.14	.18	-.24	.03	.34*	-.19*	.03	.31*	---

Table 11

<u>**The Effects of the Three Core Team Level Constructs on Team**</u>

<u>**Decision Accuracy**</u>[a]

Dependent Variable = Team Decision Accuracy

Hierarchical Step	Independent Variables	Total R^2	Incremental R^2
(1)	Hierarchical Sensitivity (HS)	.03*	.03*
(2)	Staff Validity (SV)	.21*	.18*
(3)	Team Informity (TI)	.24*	.03*
(4)	HS X TI	.24*	.00
(5)	TI X SV	.24*	.00
(6)	HS X SV	.27*	.03*

---

[a] n = 102 (one observation per team)

* p < .05

Study 2
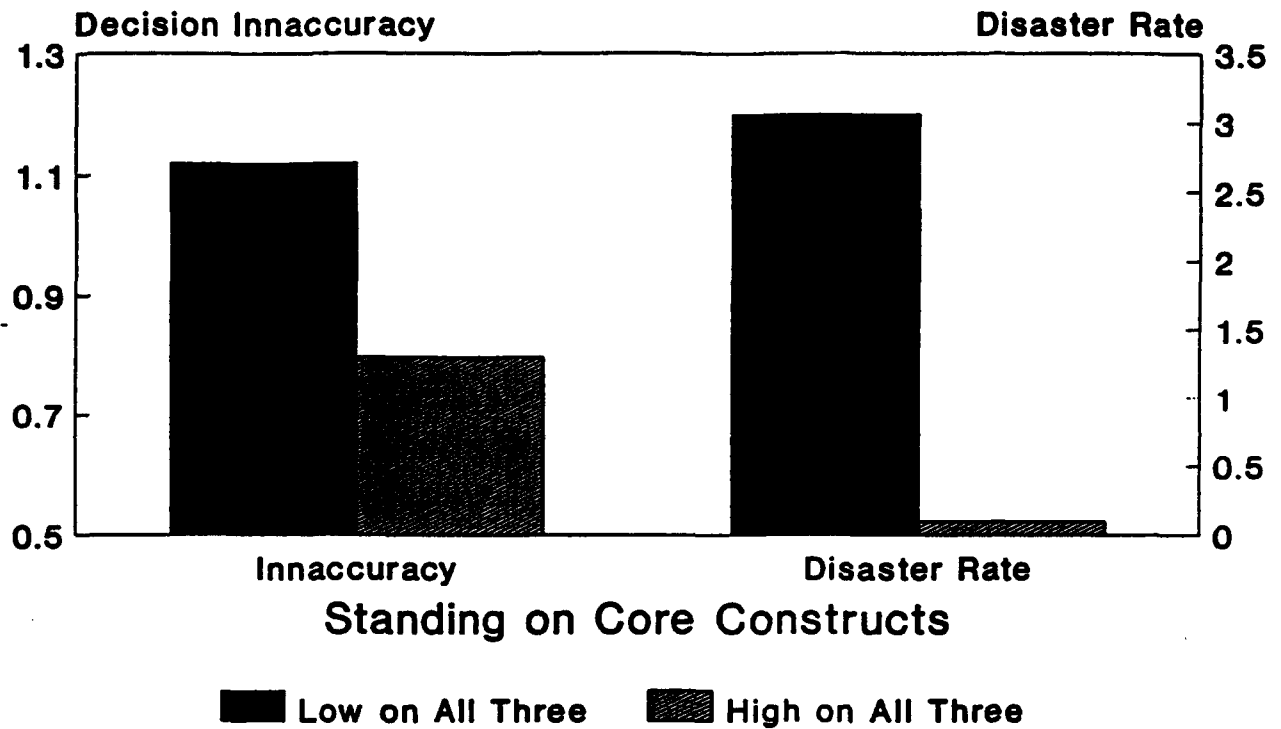## Combined Effects for Core Constructs

Figure 10. The combined effects of the core constructs on overall accuracy and disaster rates in Study 2.

team's decision was off by four or more points). Again, disasters were relatively rarely occurring events, but in Study 2, no team that was high on all three core characteristics ever experienced a disaster. That is, there were 14 teams that were high on all three core characteristics and each of these teams made 24 decisions. This generated 336 opportunities for a disaster that never took place. The 14 teams that were low on all three characteristics experienced 10 disasters, for a disaster rate of 3%. These results are plotted in Figure 10.

The Effects of the Non-Core Variables on Performance. Table 12 shows the results of regressing the non-core characteristics on decision accuracy. The effect of these variables was weaker than the effects of the core-constructs. Seventeen percent of the criterion variance was explained by these three variables and their interactions, and all of this was attributable to the main effects for cohesion and competence. As expected, teams that were low in cohesiveness and teams that contained an incompetent member performed worse than teams characterized in the opposite fashion. Thus, the buffering effects of cohesiveness and redundancy that were the focus of this study did not materialize. Neither high cohesiveness nor high redundancy was able to buffer teams from the impact of the incompetent member.

The Effects of the Non-Core Variables on Core Variables. Table 13 shows the results of regressing decision informity on the non-core variables. This analysis occurs at the decision level, and hence there are 2,448 observations (i.e., 102 teams making 24 decisions each). As is apparent, there was a strong main effect of informational redundancy on team informity, in that teams with highly redundant members were able to gather a great deal more total information than teams that were low in redundancy. There was also a small but statistically significant effect for cohesiveness in the expected direction.

Table 14 shows the results of regressing staff validity on the non-core variables. This analysis occurs at the individual level, and hence there are 270 observations (i.e., 3 staff members in each of 102 teams minus 36 confederates). In sum, 11% of the variance in the staff members validity was accounted for by the non-core variables. The main effects for cohesion explained the bulk of this variance (5%), but there were also main effects for competence and redundancy (2% each). In general, low cohesion, the presence of an incompetent colleague, and low redundancy had a negative impact on the validity of

Table 12

The Effects of the Non-Core Variables on Team Decision Accuracy[a]

Dependent Variable = Team Decision Accuracy

Hierarchical Step	Independent Variables	Total R^2	Incremental R^2
(1)	Competency (Cm)	.07*	.07*
(2)	Cohesiveness (Ch)	.17*	.10*
(3)	Redundancy (R)	.17*	.00
(4)	R X Ch	.17*	.00
(5)	R X Cm	.17*	.00
(6)	Cm X Ch	.17*	.00

---

[a] n = 102 (one observation per team)

* $p < .05$

Table 13

The Effects of the Non-Core Variables on Core Variables--

Decision Informity[a]

Dependent Variable = Decision Informity

Hierarchical Step	Independent Variables	Total R^2	Incremental R^2
(1)	Competence (Cm)	.00	.00
(2)	Cohesion (Ch)	.01*	.01*
(3)	Redundancy (R)	.36*	.35*
(4)	R X Cm	.36*	.00
(5)	R X Ch	.36*	.00
(6)	Cm X Ch	.36*	.00

---

[a] n = 2,448 (24 observations per team)

* $p < .05$

Table 14

The Effects of the Non-Core Variables on Core Variables--
Individual Validity[a]

Dependent Variable = Individual Validity

Hierarchical Step	Independent Variables	Total R^2	Incremental R^2
(1)	Cohesion (Ch)	.05*	.05*
(2)	Competence (Cm)	.07*	.02*
(3)	Redundancy (R)	.09*	.02*
(4)	R X Cm	.09*	.00
(5)	R X Ch	.11*	.02*
(6)	Cm X Ch	.11*	.00

[a] n = 204 (2 observations per team with confederates; 3 observations per team without confederates).

* $p < .05$

recommendations made by individual staff members. There was also a statistically significant effect for the cohesiveness by redundancy interaction. The nature of this interaction, revealed by plotting the means for sub-groups, indicated that the deleterious effects of low redundancy were especially strong for teams that were low in cohesiveness. Table 15 shows the results of regressing dyadic sensitivity on the non-core variables. This analysis occurs at the dyadic level, and hence there are 306 observations (i.e., 3 leader-staff dyads for each of 102 teams). In sum, only 4% of the variance in dyadic sensitivity was accounted for by the three non-core constructs. In general, low cohesiveness and the presence of an incompetent member had negative effects on dyadic sensitivity.

The Mediating Influence of the Core Level Variables. Table 16 shows the results associated with the mediational effects of the core constructs on the relationship between the non-core constructs and decision accuracy. In terms of variance accounted for, the effect of the non-core constructs (i.e., competency and cohesion) went from 17% of the variance to 4% of the variance when the core constructs were controlled--a reduction of 76%. Team cohesiveness still had a statistically significant effect on decision accuracy, however, even after controlling for the core constructs. Thus, we conclude that the effects of the non-core constructs (cohesion and competence) are largely, but not totally, mediated by the core constructs.

Discussion of Study 2

Again, the results of Study 2 supported or partially supported the main propositions of the MLT framework. As in Study 1, variables at all three lower levels of analysis (i.e., the decision level, the individual level, and the dyadic level) impacted overall team decision making accuracy. Also, as in Study 1, the three core level variables, when taken together had strong effect on performance, explaining over a quarter of the variation in team decision making accuracy. The performance of teams that were high on all three core characteristics was roughly one and a half standard deviation units above those teams that were low on all three, and teams high on all three dimensions experienced no disasters--despite having over 300 opportunities to do so. The disaster rate for teams that were low on all three dimensions was 3%.

As in Study 1, the third proposition regarding the mediating role of the core characteristics on the relationship between

Table 15

The Effects of the Non-Core Variables on Core Variables--
Dyadic Sensitivity[a]

Dependent Variable = Dyadic Sensitivity

Hierarchical Step	Independent Variables	Total R^2	Incremental R^2
(1)	Cohesion (Ch)	.01*	.01*
(2)	Competence (Cm)	.03*	.02*
(3)	Redundancy (R)	.04*	.01*
(4)	R X Cm	.04*	.00
(5)	R X Ch	.04*	.00
(6)	Cm X Ch	.04*	.00

[a] n = 252 (3 observations per team for four time periods)

* $p < .05$

Table 16

The Effects of the Non-Core Variables on Team Decision
Accuracy Controlling for the Core Variables

_____

Dependent Variable = Team Decision Accuracy

_____

Hierarchical Step	Independent Variables	Total R^2	Incremental R^2
(1)	Hierarchical Sensitivity	.03*	.03*
(2)	Staff Validity	.21*	.18*
(3)	Team Informity	.24*	.03*
(4)	HS X SV	.27*	.03*
(5)	Competence	.28*	.01
(6)	Cohesion	.31*	.03*

non-core characteristics and team decision making accuracy was only partially supported. Although controlling for the core characteristics attenuated the effects of the non-core characteristics substantially (76%), it did not drive these effects to zero. In particular, team cohesiveness had significant effects on team decision making accuracy that were not attributable to the core constructs.

Although the results from Study 2 generally supported the MLT framework and at least partially replicated the effects documented in Study 1, there were also several differences in the results of these two studies. These differences and the implications of these results for theory and practice in the realm of decision making teams are discussed below.

Conclusions

The purpose of this project was threefold. First, it was to develop a theory or model of team decision making in particular kinds of teams working under fast-paced conditions in continuous task performance settings. A defining characteristic of such teams was that of having a hierarchical authority structure and expertise distributed among team members. Furthermore, it was expected that the pace of the demands for reaching decisions and the nature of the decisions themselves would be such that those working under such conditions would experience some degree of stress as they attempted to make decisions which had some personal consequences to them. This theory has been presented earlier in this report.

A second purpose was to develop a team decision making exercise for evaluating the accuracy of team decisions. TIDE^2 is such an exercise. In this report, we have described a command and c i.trol configuration of the exercise focused on deci... involving the level of threat represented by aircraft in an airspace monitored by a four person team. In our opinion, TIDE^2 functions very well for studying team decision making processes under such conditions. It creates conditions in which team members become quite involved; it allows for the manipulation of key variables; and data generated in the exercise are measured and stored in ways that can be retrieved for later analyses. In addition, although not discussed in this report, the software for the exercise was created to allow for considerable flexibility in configuring problems for teams. The exercise can be used to study team decision making for teams of managers, physicians, educators, task forces, or any other four person team of experts who must obtain

information on multiple dimensions, share that information in some way, and reach decisions. For a complete description of the program, see Hollenbeck et al. (1991).

The third purpose was to collect empirical data directed toward evaluating the theoretical position taken here with respect to its ability to predict the decision making accuracy of teams that performed on the exercise. Results from two empirical studies reported here were supportive of several aspects of the theory. First, with respect to levels, consistent with the first proposition, we found that factors at all four levels related to decision making accuracy. At the decision level, it was critical that teams collect and distribute as much information as they could for each of the decision objects they encountered (i.e., high in decision informity). At the individual level, teams staffed with members who were adept at translating raw data in their area of expertise into valid recommendations made better decisions. At the dyad level of leader-member interaction those leaders who appropriated weighted staff members' recommendations made better decisions (i.e., high dyadic sensitivity).

The second proposition was directed at the team level, hypothesizing a relationship between the three core level team constructs and team decision making accuracy. Here again the results were consistent with the theory. Across the two studies, the three core team-level constructs consistently related to decision accuracy in the hypothesized direction and explained a large amount of variance (roughly 25-50%). Combining the results for the three variables by comparing the performance levels of teams that were high on all three characteristics to teams that were low on all three revealed large differences in accuracy, both at a general level (i.e., 1.5 to 2.0 standard deviation units) and in terms of avoiding the most serious errors in decision making (i.e., disaster rates)

In terms of the third proposition, there was partial support for the mediational role of the core constructs on relationships between non-core constructs and decision accuracy. Across the studies, 67% to 76% of the effect for non-core variables (e.g., experience, cohesiveness, and staff competency) was eliminated when the core constructs were controlled statistically. The core constructs did not, however, totally mediate the effects of these variables. There were still some small, but statistically significant relationships between several non-core variables and decision accuracy despite controlling for the core variables.

Although there were many general consistencies across the two studies, there were some differences worth noting. First, in general, the amount of variance accounted for by the core constructs in the first study was larger than that in the second study. We believe that this was due to two factors. First, because the measures of core constructs derived in Study 1 were based on a larger number of decisions (127 versus 24), these measures were probably more reliable than the measures obtained in Study 2, thus enhancing the magnitude of relationship. Second, the smaller amount of variance accounted for in Study 2 can also be explained by the fact that this study only examined between team differences. As Study 1 clearly showed, there were important within team factors that accounted for variance in both decision accuracy and the three core team-level constructs. This is probably best captured by the different effect sizes for the team informity variable, which accounted for 22% of the criterion variance in Study 1, but only 4% in Study 2. Recall, that, of the three core team level constructs, team informity was the one variable that varied most within teams (87% of the variance in this variable was attributable to within team differences versus 13% that was due to between team differences). Thus, Study 2, which obtained only one observation per team (and hence could not assess within team variance) was probably less powerful for examining relationships associated with this aspect of MLT.

On the other hand, Study 2 found a much stronger relationship for staff validity than Study 1. Of the three core constructs examined in Study 1, this was the one most susceptible to between team variation (60% versus 40%). Moreover, the amount of variation in this variable was enhanced in Study 2 relative to Study 1 because of a direct manipulation that set the validity of one of the staff members in some of the teams to near zero. The overall conclusion to derive from this discussion is that it will probably be impossible to make generalized predictions about which of the three core team- level variables is "most important." Importance will likely vary, depending upon the nature of the study (within versus between), the nature of variables manipulated, and the context in which the decisions occur.

It is also worth noting that whereas both studies were able to document an interaction between staff validity and hierarchical sensitivity, the nature of this interaction varied slightly. Study 1 suggested that the two variables interacted in a way that indicated that both were "necessary" for high performance. That is, teams that were

high on both variables were significantly more accurate than teams that were low on both or either one separately. On the other hand, in Study 2, the variables interacted in a such a way that   high on either one was apparently sufficient.

One explanation for the differences between studies is that there was potentially a differential "ceiling" and "floor" associated with studies because of their longitudinal versus one-time nature. The longitudinal nature of Study 1, which gave teams 127 opportunities to improve on the task, might have created a performance floor, such that even teams low on both validity and sensitivity floor performed well enough to be comparable to teams that were high on just one of the variables. On the other hand, Study 2, which provided teams with only 24 opportunities to learn, might have imposed a ceiling such that the teams that were high on both variables were still comparable to teams that were high on only one or the other.

Rather than seeing differences between the studies as limitations, we feel that detecting these kinds of differences highlights one of the major advantages of combining these two studies into one overall research project. Conducting either one alone might have provided an inaccurate picture of what could and could not be generalized from the results of the empirical tests of this theory (e.g., the amount of variance accounted for by the core team level variables, the relative magnitude of the effects for one core level construct versus another, or the nature of the validity sensitivity interaction).

Also, by combining the studies we were able to generate tests of the theory with complimentary strengths and weaknesses. The strength of Study 1 was in its ability to test the theory in an environment where we could closely monitor the development of a small number of teams (21) that made a large number of decisions (127) over a lengthy time period (6 weeks). It also overcame a common weakness of team research, that of using ad hoc teams of people who work together for only one time. The small number of teams, however, was an obvious limitation. The strength of Study 2, on the other hand, was its ability to test the theory in a much larger sample of teams (102). Studying this many teams, however, obviously precludes the ability to monitor them for a long duration, which again fed into the strength of Study 1.

Finally, combining the two studies allowed us to explore a larger sample of non-core variables and investigate their

effects on core variables than would have been feasible in a
single study. For example, the two empirical studies
combined here represent a rather large investment in terms
of time and financial resources. In terms of time, Study 1
entailed over 1,000 "subject-hours" (21 teams x 4 persons
per team x 4 different sessions x 3 hours per session =
1,008 hours). Study 2 entailed over 1,200 "subject-hours"
(102 teams x 4 members per team x 1 session x 3 hours per
session = 1,224 hours). Since subjects were paid both per
hour and with bonuses for high performance, the 2,200
"subject-hours" that went into this research represents a
rather large financial investment. It was the belief of the
research team, that it was better to divide up these
resources into two complimentary studies of a different type
that were able to examine six different "non-core"
variables, relative to one giant study that could have only
examined three "non-core" variables.

Finally, the theory proposed here is one that addresses team
decision making in hierarchical teams with distributed
expertise from the standpoint of key elements we believe are
necessary for reaching accurate team-level decisions. The
elements provide the structure for the theory of team
decision making. In particular, informity, staff validity
and hierarchical validity are hypothesized to be three
structural outcomes of the team decision making process that
are combined to lead to team decision accuracy.

Similarly, the non-core variables in the outer ring of the
model are structural variables believed to impact on team
process, and their impact is seen as filtering through the
core constructs. The fact that the data reported here
showed that non-core variable effects were not completely
mediated by core constructs in terms of the non-core
variables' effects on decision accuracy implies that the
core structure is somewhat incomplete as suggested by the
theory. However, in support of the theory, the partially
mediated effects were quite large.

Although the core constructs are assumed to result from team
level processes, we have purposefully left unspecified a
number of team processes that lead to the core constructs.
We have done this because we believe that there are a large
number of complex processes at work in such teams, and
because different situational non-core constructs are likely
to evoke very different constructs that will be relevant in
different settings. In any given setting, some processes
are likely to be more relevant than others. By leaving the
theory open as to the processes, those that are likely to be
more relevant can be explored within the particular setting
and problem addressed. Future work with the team exercise
and theory will address more of these issues.

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Author Notes

Footnote

[1]There was one exception in a familiar team whose randomly-selected member absolutely refused to change teams. After a lengthy stalemate, another member of this team agreed to switch teams. Given the small sample, and the time already invested in this team, this was considered a worthwhile trade-off, when compared to removing the team from the study.

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Technical Reports

1. Hollenbeck, J. R., Sego, D. J., Ilgen, D. R., & Major, D. A. (1991). <u>Team interactive decision exercise for teams incorporating distributed expertise (TIDE^2): A program and paradigm for team research</u>. Technical Report 91-1, E. Lansing, MI:Michigan State University.

2. Ilgen, D. R., Major, D. A., Hollenbeck, J. R., Sego, D. J. (1991). <u>Decision making in teams: Raising an individual decision making model to the team level</u>. Technical Report 91-2, E. Lansing, MI: Michigan State University.

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11. Ilgen, D. R. (1992, May). Team decision making research and theory. Symposium organized by the author. Annual meeting of the Society for Industrial and Organizational Psychology, Montreal.

12. Major, D. A., Sego, D. J., Hollenbeck, J. R., & Ilgen, D. R. (1992, May). Decision making in teams with distributed expertise. Presented at the annual meeting of the Society for Industrial and Organizational Psychology, Montreal.

13. Ilgen, D. R., Hollenbeck, J. R., Sego, D. J., Major, D. A., Phillips, J., & Hedlund, J. (1992, June). Team member abilities and problem solving strategy effects on team decision making outcomes and processes in teams with distributed expertise. BRG Symposium, Monterey, CA.

14. Sego, D. J., Hollenbeck, J. R., Ilgen, D. R., Major, D. A., (1992, August). Team decision making accuracy within three different base rate conditions. Paper presented at the annual meetings of the American Psychological Association, Washington, DC.

15. Hollenbeck, J. R., Sego, D. J., Ilgen, D. R., & Major, D. A. (1992, September). Team decision making under stressful conditions: Construct validation of potential manipulations and measures from the TIDE^2 simulation. Paper to be presented at team conference at the University of South Florida.

16. Ilgen, D. R. (1993). Team decision making: Theory, Method, and Results. Invited presentation to the annual Nags Head Conference on Groups and Organizational Effectiveness, Boca Raton, FL.

17. Ilgen, D. R. (1993, October). Team-level constructs of team decision making: Informity, staff validity, and hierarchical sensitivity. Presented at the annual meetings of the Society for Organizational Behavior, Virginia Beach, VA.

18. Hollenbeck, J. R. (1993, May). Cognitive science and team decision making: A new paradigm. Invited presentation for the winner of the E. J. McCormick Award for Distinguished Early Career Contributions to Industrial and Organizational Psychology. Annual meetings of the Society of Industrial and Organizational Psychology, San Francisco.

Invited Talks

19. Ilgen, D. R. (1991, February). Team research in the 1990s. Invited presentation for Festschrift honoring the retirement of Fred E. Fiedler, Claremont-McKenna College, The Claremont Colleges, Claremont, CA.

20. Ilgen, D. R. (1991, March). Team research in the 1990s: Making progress and avoiding past failures. University of Western Australia, Perth, Western Australia.

21. Ilgen, D. R. (1991, March). Team research in the 1990s. Bond University, Cold Coast, Queensland, Australia.

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30. Hedlund, J. (1993). <u>Computer-mediated versus face-to-face communications in hierarchical team decision making</u>. Unpublished masters thesis, E. Lansing: Michigan State University (Degree to be awarded in December).

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